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Illinois Sustainable Technology Center

Monitoring and Documenting the Performance of Stormwater Best Management Practices

Center for Neighborhood Technology
with Hey and Associates

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We also wish to acknowledge the very fine and meticulous work done by our partners Jeff Wickenkamp and Deanna Doohaluk of Hey and Associates Inc., whose experience with infiltration testing and performance monitoring was invaluable.

This work depended on the participation of knowledgeable people who worked with us to locate appropriate sites and construct green infrastructure features for the research. Peter Mulvaney from the Chicago Department of Water Management suggested approaching churches that had experienced recurring flooding. Pastor Mel Hermanns of Our Lady Gate of Heaven Parish was patient as our tenacious contractor, Joseph Jackson, battered through 18 in of steel slag to build the bioswale. And at St. Margaret Mary Parish, we were fortunate to find a fine team of partners. Pastor Jim Barrett insisted that his bioswale and rain gardens (where research ended in 2008) be placed at the front door of the rectory. Facilities Manager Jack Kent worked diligently and in good spirits with us until near his death. And Principal Peggy Finnegan thoroughly enjoyed having dozens of students working in the dirt to plant and care for the bioswale. It was especially satisfying to know that our permeable pavement patches have relieved the church properties of the frequent flooding that they had suffered for decades.

The CNT team consisted of Bill Eyring, Project Manager; Kalle Butler Waterhouse, Natural Resource Consultant; and Steve Wise, Natural Resources Program Manager. Cindy Copp and Tim Lang created and managed the green infrastructure inventory map at www.greenmapping.org.

About the Center for Neighborhood Technology

The Center for Neighborhood Technology (CNT) is an award-winning innovations laboratory for urban sustainability. Since 1978, CNT has been working to show urban communities in Chicago and across the country how to develop more sustainably. CNT promotes the better and more efficient use of the undervalued resources and inherent advantages of the built and natural systems that comprise the urban environment. As a creative think-and-do tank, we research, promote, and implement innovative solutions to improve the economy and the environment; make good use of existing resources and community assets; restore the health of natural systems; and increase the wealth and well-being of people—now and in the future. CNT's unique approach combines cutting edge research and analysis, public policy advocacy, the creation of web-based information tools for transparency and accountability, and the advancement of economic development social ventures to address those problems in innovative ways. CNT works in four areas: transportation and community development, water, energy, and climate. CNT has two affiliates, I-GO™ Car Sharing and CNT Energy. CNT was a recipient of the 2009 MacArthur Award for Creative and Effective Institutions. More information about CNT is available at www.cnt.org.

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Abstract

The Center for Neighborhood Technology (CNT) and Hey and Associates (Hey) worked under the support of the Illinois Sustainable Technology Center (ISTC) to monitor and document the performance of stormwater best management practices during 2009 and 2010. There were three components of the project: (1) we conducted real-time monitoring on a bioswale and two patches of permeable concrete and documented the results, (2) we developed and implemented an inventory of green infrastructure features throughout the 6-county Chicago Region, and (3) we selected 15 rain gardens for infiltration testing and three of those for additional synthetic drawdown testing and documented the results.

The most important results can be summarized as follows:

- A bioswale can be an effective method of infiltrating stormwater from a large impervious surface. The limits to its performance may be the permeability of underlying soils. However, if there are existing drainage structures to serve as a backup system, the bioswale can be utilized with confidence.
- Permeable pavement can also be an effective method of infiltrating stormwater from a parking lot. It can be utilized with confidence if it is placed so that it surrounds existing drainage structures and if there is a maintenance program that prevents clogging.
- Rain gardens can be an effective method of infiltrating stormwater from a roof or other impermeable surface. While soil conditions vary greatly throughout the region, and often vary substantially within a single rain garden, rain gardens can be used with confidence as long as caution is taken not to divert water toward a vulnerable situation.
- Despite the many reasons often given to doubt the capacity of our soils to infiltrate stormwater, rain gardens are nearly always successful. For example, one measure of success could be the capacity of a rain garden to infiltrate a 100-year storm event from a tributary area six times larger than the garden. Thus, a garden could be considered effective if it infiltrates seven inches of rainfall from an area six times the garden’s area plus the area of the rain garden, or the equivalent of 49 inches during a 24-hour storm. Our testing indicated that all but one of the 15 rain gardens tested would successfully infiltrate the water from a 100-year storm event.

Executive Summary

Traditional development and infrastructure has treated stormwater as a nuisance that is quickly ducted to detention basins (when local ordinances insist) and then to streams. The Center for Neighborhood Technology (CNT) believes that a more sustainable solution involves the strategic use of “green infrastructure.” Green infrastructure is sustainable because it utilizes stormwater as a resource that, combined with other natural features of the landscape, creates value for communities while reducing damages due to pollution and flooding. It is community-based because it brings people together with the common purpose of solving problems while improving their community’s environment as well as their living conditions. Small-scale green infrastructure features are often referred to as best management practices (BMPs) for stormwater management.

More widespread utilization of green infrastructure, however, is impeded by a lack of data concerning how well these BMPs perform immediately after installation, how they perform over time, and how frequently maintenance may be required.

CNT was provided a grant in January, 2009, by the Illinois Sustainable Technology Center (ISTC) for “Monitoring and Documenting the Performance of Stormwater Best Management Practices.”

The ISTC project was based on CNT’s hypothesis that:

> Green Infrastructure landscape features (vegetated swales, bioswales, rain gardens and permeable pavement) are effective methods of reducing stormwater runoff and downstream pollution loads, and their performance can be quantitatively documented for use in engineering design, a time consuming and unpredictable process.

The goals of the project were:

1. Develop performance data for green infrastructure features that meet engineering standards for design and permitting.
2. Develop a Green Infrastructure Site Inventory for the Chicago Region that is accessible to the public.
3. Make the project results available to a wide audience of users, agencies, and interested parties.

Bioswale Performance Monitoring

The purpose of the bioswale performance monitoring program at Our Lady Gate of Heaven Parish was to gather data to measure the performance of bioswales in the winter months. This effort was the continuation of bioswale performance monitoring conducted at Our Lady Gate of Heaven during 2007 and 2008 for a different project. The data collected between December 15, 2009, and February 9, 2010, indicated that the winter conditions did not negatively impact the performance of the bioswale. As observed during the summer months, the infiltration rate of the swale during the winter months was limited by the infiltration rate of the subsoils and not of the engineered soils or aggregate, indicating that frozen surface conditions do not negatively impact the infiltration rate of the bioswale.

We concluded that a bioswale can be an effective method of infiltrating stormwater from a large impervious surface. The limits to its performance may be the permeability of underlying soils. However, if there are existing drainage structures to serve as a backup system, the bioswale can be utilized with confidence.

Permeable Concrete Performance Monitoring

In 2007, under a previous CNT project, two permeable concrete patches were installed in a parking lot owned by St. Margaret Mary Parish. These infiltration rates were acceptable, although recent improvements in the paving design have now yielded significantly higher rates. The results in 2009 indicated that a routine cleaning schedule may be required to maintain the functionality of permeable pavement sections. If the parking lot is designed so that the entire surface of the permeable pavement is covered with water during major rain events, significant reductions in the flow to the sewer may be attainable.

Permeable pavement can also be an effective method of infiltrating stormwater from a parking lot. It can be utilized with confidence if it is placed so that it surrounds existing drainage structures and if there is a maintenance program that prevents clogging.

Green Infrastructure Inventory

CNT initiated the Green Infrastructure Site Inventory in February 2010. The number of responses to the survey was somewhat disappointing, although reminders helped. Far more effective were personal inquiries, networking, and discussions at watershed meetings. All of these methods will continue to be utilized on an ongoing basis to increase the number of green infrastructure features in the inventory. The number of features that were identified during 2010 grew steadily and at the end of that year totaled 276 features, including 76 rain gardens, 56 native landscapes, 32 permeable pavement BMPs, and 28 bioswales. After confirming most of the sites with visual surveys, a total of 82 sites were selected for the initial inventory.

A data layer displaying these sites has been prepared for http://greenmapping.org so that anyone can learn where the sites are and visit them to gain information that can lead to their replication throughout the region. The map with the 82 sites can be seen on the website above by selecting “Interactive Map” and then “Green Infrastructure Demonstration Sites.” By clicking on a site, the user sees the address, a brief description (including a website link when available), and, for most sites, a photograph of the site.

The database will include all of the known sites, not just those shown on the map, so that the cumulative impact of all sites can be estimated when that is desired. We will continue to employ direct communications as well as the survey instrument to locate additional sites.

About a third of the sites that were identified through the survey turned out not to be suitable for the map. Some were never located in the field, others were inaccessible, and others were not green infrastructure. Currently, the Inventory Map includes 82 sites with another 80 or so awaiting confirmation. We are sure there are hundreds more yet to be located and we project that the numbers will grow rapidly in the future.

A visual inspection of the identified features was accomplished by visiting each of them and utilizing an assessment checklist that was adapted from that of the University of Minnesota Stormwater Management Practice Assessment Project. While there were many indications that additional maintenance was needed, none of the 70 green infrastructure features that were assessed showed signs of unsatisfactory performance.

Rain Garden Performance Monitoring

Infiltration rate tests were performed at 15 rain gardens using a custom-made 10-cm diameter infiltromenter. Sixty-one (61) infiltration tests were conducted in the 15 rain gardens. The time required for each individual test to be completed ranged from 30 s to 28,443 s (7 hr 54 min) with an average infiltration time of 2,607 s (34 min 27 s). Ninety-two percent (92%) of the tests were completed in less than one hour. Only one of the tests was terminated due to a minimal change in water level over a three-hour period.

From the 15 sites evaluated using the infiltration tests, three rain gardens were selected for synthetic drawdown testing. These rain gardens were selected, in part, because of the willingness of the owner/operator to provide a water source for the filling of the rain garden. The synthetic drawdown tests were difficult to implement and the tests yielded little data of value.

The following points summarize our findings from the infiltration testing:

- High variability of K_{sat} values was found when comparing testing locations within rain gardens. This variability was even seen in rain gardens constructed of engineered soils where soil conditions are expected to be similar throughout the garden.
- Lower infiltration rates were observed near the inflow and in the deepest portions of the rain gardens. These findings suggest that surface infiltration may decrease over time in these areas due to compaction of the soils caused by concentrated flows or the clogging of the surface soils through particle settling.
- High variability of average K_{sat} values was found across the 15 tested rain gardens.
- Rain gardens that were constructed with engineered soils had higher K_{sat} values than rain gardens that were constructed in native soils.

Although the rain gardens constructed with engineered soil had higher average K_{sat} values than rain gardens that were constructed in native soils, all but one of the native soil rain gardens performed better than would be predicted using Natural Resources Conservation Service (NRCS) soil survey data.

We concluded that rain gardens can be an effective method of infiltrating stormwater from a roof or other impermeable surface. While soil conditions vary greatly throughout the region, and often vary substantially within a single rain garden, they can be used with confidence as long as caution is taken not to divert water toward a vulnerable situation.

Despite the many reasons often given to doubt the capacity of our soils to infiltrate stormwater, rain gardens are nearly always successful. For example, one measure of success could be the capacity of a rain garden to infiltrate a 100-year storm event from a tributary area six times larger than the garden. Thus, a garden could be considered effective if it infiltrates seven inches of rainfall from an area six times the garden's area plus the area of the rain garden, or the equivalent of 49 inches during a 24-hour storm. Our testing indicated that all but one of the 15 rain gardens tested would successfully infiltrate the water from a 100-year storm event.

Introduction

Northeastern Illinois faces a variety of challenges related to stormwater and other water resource management. The vast extent of impermeable surfaces in urban areas, and the constant expansion of such surfaces, results in enormous challenges to protect communities from flooding and to restore natural habitats to healthy environments.

Traditional development and infrastructure has treated stormwater as a nuisance that is quickly ducted to detention basins (when local ordinances insist) and then to streams. The Center for Neighborhood Technology (CNT) believes that a more sustainable solution involves the strategic use of "green infrastructure." Green infrastructure is the interconnected network of open spaces and natural areas (such as greenways, wetlands, parks, forest preserves, and native plant vegetation) that naturally recharges aquifers, improves water quality, and provides recreational opportunities and wildlife habitat. In urban areas, the natural features can be supplemented with small-scale landscape features – rain gardens, vegetated swales, and native plantings – that provide the same water management functions. These small-scale green infrastructure features are often referred to as best management practices (BMPs) for stormwater management.

Green infrastructure is sustainable because it utilizes stormwater as a resource that, combined with other natural features of the landscape, creates value for communities while reducing damages due to pollution and flooding. It is community-based because it brings people together with the common purpose of solving problems while improving their community's environment as well as their living conditions.

Communities and stormwater management agencies around Illinois and the country are increasingly considering the use of green infrastructure best management practices – also known as Low Impact Development techniques – to capture and filter stormwater on site.

More widespread utilization of green infrastructure, however, is impeded by a lack of data concerning how well these BMPs perform immediately after installation, how they perform over time, and how frequently maintenance may be required.

Previous Research

CNT, during 2007 and 2008, managed two projects to monitor performance of green infrastructure BMPs – "A Sustainable Community-Based Approach to Reducing Non-Point Pollution," funded by the Illinois Environmental Protection Agency (IEPA) under the 319 Program, and "Green Infrastructure Data Quantification and Assessment" funded by the U.S. Environmental Protection Agency (USEPA) (together referred to as "the Research Projects"). The Research Projects built green infrastructure facilities and collected one season's data on their performance. The Research Projects were designed to provide engineering performance data that can be used to design such facilities to meet regulatory objectives to manage stormwater. Local agencies require local BMP performance data to evaluate whether such facilities will be as effective in the local environment as have facilities in other regions where their performance has been documented.

The facilities that were monitored during 2007 and 2008 for the Research Projects were two Chicago parking lot bioswales of 660 and 900 ft^2, four rain gardens of from 100 to 200 ft^2 each, and a 250 linear ft vegetated swale in Lake County. The initial funding for the Research Projects ended in late 2008.

Current Research

The Center for Neighborhood Technology (CNT) was provided a grant in January 2009 by the Illinois Sustainable Technology Center (ISTC) for "Monitoring and Documenting the Performance of Stormwater Best Management Practices."

This project extended the length of quantitative monitoring for four green infrastructure best management practices (BMPs) in the Chicago area to determine their effectiveness for sustainable stormwater management. The initial monitoring began in 2007 for two parking lot bioswales, four rain gardens, and a vegetative swale.

This ISTC project continued the monitoring of one bioswale, two rain gardens, and two patches of permeable pavement. Hey and Associates (Hey) was the monitoring consultant for all of this work.

CNT had proposed to locate an additional vegetated swale to be monitored during 2009 and 2010, but was unable to identify a swale that could be adapted so that inlet and outlet conditions could be monitored reliably. After considering the reduced likelihood that further searching would be successful, and a realization that the data gained would not be frequently utilized, CNT and Hey offered a suggestion to the ISTC to include a set of new tasks in this project.

In 2009, this project was modified, without additional funding, so that CNT and Hey were able to accomplish two additional tasks:

- A Green Infrastructure Site Inventory for the 7-county Chicago Region, including a search for all of the rain gardens, bioswales, and permeable pavement and development of a map and database for documenting the inventory.
- Monitoring of 15 additional rain gardens and bioswales utilizing a monitoring protocol developed by the University of Minnesota.

Methods and Analysis

Monitoring of Existing Best Management Practices

The existing sites that were suggested for monitoring in the March 2008 proposal to the ISTC were:

1. The bioswale at Our Lady Gate of Heaven Parish in Chicago (see Figure 1)
2. The bioswale at St. Margaret Mary Parish in Chicago
3. The two rain gardens at St. Margaret Mary Parish

The bioswale at Our Lady Gate of Heaven had been monitored during 2007 and 2008, and additional monitoring was recommended as the ISTC project commenced. Instrumentation was installed and monitoring was conducted between December 1, 2009, and March 31, 2010.

Figure 1: Details of the Bioswale at Our Lady Gate of Heaven Parish, including three monitoring wells

The bioswale and both rain gardens at St. Margaret Mary demonstrated during the 2008 monitoring that they had the capacity to infiltrate stormwater from any storm up to at least six inches without a significant increase in saturated water level. Because monitoring of these facilities would not have yielded additional data of value, CNT recommended in early 2009 that additional sites be selected to replace these specific facilities at St. Margaret Mary.

The additional sites that were suggested for monitoring in the March 2008 proposal to the ISTC included two permeable concrete patches that had been installed at St. Margaret Mary Parish during 2007 (Figure 2). The instrumentation was installed in the permeable concrete patches and monitoring was conducted between July 21, 2009, and March 18, 2010.

It was also proposed that a second vegetated swale would be located in the Chicago area and equipped for monitoring. So, during 2009, CNT also sought candidate sites for a vegetated swale for use in the project.

Figure 2: A Permeable Pavement Patch at St. Margaret Mary Parish

The criteria for selection included:

- a swale with dimensions on the same order of magnitude as those of the Lake County swale that was monitored in 2008 – length of at least 250 ft, wetted width of from a few feet to up to 50 ft, and vegetation that was dense and mature
- a location where we could install and regularly maintain monitoring equipment for both water quantity and water quality
- a source of stormwater that could represent the quality of water leaving a highway right-of-way or other urban drainage area.

We made numerous inquiries to knowledgeable individuals and received suggestions from the Illinois Toll Highway Authority, the Forest Preserve District of Cook County, and others. Based upon field inspections and discussions with other researchers having related goals, no acceptable site for the vegetated swale was ever identified.

We also recognized that the Lake County swale was ideal for gaining additional data, except for a single criterion – during 2008 the water entering the swale was of such high quality that no improvement could be identified at the outlet. During 2007 water quality at the inlet had been much poorer. CNT evaluated methods of temporarily reducing the quality of inlet flows during storms which would have resulted in conditions ideal for determining the effectiveness of a vegetated swale to improve water quality. One of the methods we considered was to agitate a small upstream pond to suspend particulates, but the pond was in the front yard of private property so that was not possible. We also considered adding nutrients to the stream upstream of the swale, but that would have impacted the pond or would have required adding pollutants in the right-of-way of a township road. Also, there is a pond in a forest preserve downstream of the swale, which could have been impacted by additional nutrients. Therefore, none of the methods were found to be feasible.

In order to identify any permeable pavement sites that could be utilized to replace the two rain gardens and bioswale at St. Margaret Mary that we were no longer monitoring, we contacted the City of Chicago and other property owners who had permeable concrete or asphalt or other permeable designs, as well as manufacturers of these products. We also evaluated the benefits to be gained by continuing the monitoring of the two rain garden facilities in the Village of Bellwood. After considering potential sites, we concluded that none of these options would be of value to the users of our reporting.

Bioswale Performance Monitoring at Our Lady Gate of Heaven Parish

The purpose of bioswale performance monitoring program at Our Lady Gate of Heaven Parish was to gather data to measure the performance of the bioswale in the winter months. This effort was the continuation of bioswale performance monitoring conducted at Our Lady Gate of Heaven from October to November 2007 and April to October 2008. The bioswale is located in the parish parking lot at 2230 E. 99th Street, Chicago. It is 3 m (10 ft) wide and 19.8 m (65 ft) long and collects water from the west side of the parking lot. The drainage area of the bioswale, including its own area, totals 1,155 m^2 (12,433 ft^2). The depth of its excavation was 0.91 m (3 ft) and contains layers of sand and stone covered by 30 to 45 cm (12 to 19 in) of amended soil. Over 100 native plants help maintain the infiltration capacity of the bioswale.

Following the collection of the initial data in 2007 and 2008, several presentations detailing our findings were given to municipal engineers, planners, and other individuals who routinely make decision regarding the installation of green infrastructure. Following these presentations, it was frequently asked if there was available date on the performance of bioswales during the winter months because it was a concern that freezing conditions would negatively impact infiltration rates in the bioswales. At that time, the questions on winter performance could not be answered as monitoring during the winter of 2007/2008 was not conducted due to the monitoring equipment utilized in the study not being designed for use in below freezing temperatures. Given the interest in winter performance, it was determined that as part of this ISTC study, it would be worth the risk of equipment damage to determine if the bioswale performed similarly during winter as it did during other times of the year.

The intent of the monitoring was to assess surface infiltration rate, subsoil infiltration rate, and expected performance of the bioswale during the winter months. A monitoring system was designed and installed in the bioswale. The monitoring system included a weather station and a groundwater monitoring well.

A Hobo Weather Station Range Gauge Smart Sensor (tipping bucket rain gauge) was installed and maintained in order to obtain site-specific rain data. The rain gauge was mounted to a weather mast located on the roof of the school building. A barometric pressure meter was also located on the same weather mast as the rain gauge. The rain gauge and barometric pressure meter were configured to record data on a 5-minute interval. Data was downloaded from the rain gauge and barometric pressure meter at least once every 30 days. Rainfall data and barometric pressure data was collected between December 1, 2009 through February 9, 2010. Data was not collected after February 9, 2010, as the meter ceased to function properly. It was assumed that the meter was damaged from the below freezing conditions. All rain gauge and barometric pressure data was managed using Microsoft Excel. It should be noted that tipping bucket rain gauges tend to underestimate the amount of snowfall. However, the gauge did provide useful data to the relative amount of snowfall in a given storm. The site-specific rainfall data in conjunction with the tributary area computed from the design plans, field observation, and field survey was utilized to develop the inflow portion of a water budget. The barometric pressure data was used to calibrate the data from the water level meters installed at Our Lady Gate of Heaven and Margaret Mary. The water level meters are discussed below.

In addition, one groundwater monitoring well equipped with a Hobo Water Level Logger (water level meter) was installed in the bioswale. The groundwater well is approximately 213 cm (84 in) in length and is installed to a depth of 152 cm (60 in) below ground surface. The well is slotted from approximately 71 cm (28 in) below the ground surface to approximately 152 cm (60 in) below the ground surface, and the water level meter is installed within the slotted area. The water level meters were configured to record data on a 5-minute interval and data was downloaded from the water level at least once every 30 days. Water level data was collected between December 1, 2009, through March 31, 2010, and was managed using Microsoft Excel. The original monitoring conducted from October to November 2007 and April to October 2008 utilized two additional wells. These wells were not used in this study because the wells were placed 15 cm (6 in) above the ground surface and 15 cm (6 in) below the ground surface, which would leave them extremely susceptible to freezing conditions and potential damage.

In previous monitoring at Our Lady Gate of Heaven, a Hobo Weather S-SMA Station Soil Moisture Smart Sensor (soil moisture meter) had been installed in the bioswale. However, in the fall of 2008, the data recorder for the soil moisture meter was damaged by water and rendered inoperable. Therefore, a soil moisture meter was not used in this round of data collection.

Permeable Concrete Monitoring at St. Margaret Mary Parish

In 2007, two permeable concrete patches were installed in a parking lot owned by St. Margaret Mary Parish. The parking lot is located north of the St. Margaret Mary Activity Center on the southeast corner of the intersection of North Claremont Avenue and West Jarvis Avenue in the Rogers Park neighborhood of Chicago. The parking lot is 41.5 m (136 ft) by 19.5 m (64 ft) in size. The permeable pavement patches were retrofits to an existing parking lot. In order to install the permeable pavement, 4.6 by 4.6-m (15 by 15-ft) sections of asphalt centered on the existing storm sewer manholes were removed down to base course and replaced with permeable concrete patches. The permeable concrete sections are referred to by their general location in the parking lot – east permeable concrete section and west permeable concrete section. Combined, the east and west permeable concrete sections comprise approximately 5% of the total parking lot area. Additionally at the time of the installation of the permeable concrete, a monitoring well was installed in each permeable pavement section. The monitoring well consisted of a slotted 7.6-cm (3-in) PVC-pipe with a slotted lid. No other features (slope, manholes, etc.) were altered when the permeable pavement was installed.

The project included four assessment approaches to evaluate the performance of the permeable concrete:

1. *Infiltration Testing*

In order to determine the infiltration rate of the permeable concrete, on July 21, 2009, and October 21, 2009, infiltration testing was conducted using a single-ringed infiltrometer on each of the two permeable concrete sections.

2. *Surface Infiltration Capacity Testing*

Following the infiltration testing conducted on July 21, 2009, Hey conducted a literature search on permeable pavement testing in preparation for possibly expanding permeable pavement testing in 2010. After reviewing differing methods for infiltration testing on permeable pavements, Hey decided to modify the surface infiltration testing methods at St. Margaret Mary and use a surface infiltration capacity (SIC) testing method used by the University of New Hampshire Stormwater Center (Briggs, 2006). Surface infiltration capacity testing was conducted on November 13, 2009, and March 18, 2010.

3. *Flowpath Assessment*

In order to approximate the flow patterns of the parking lot, a flowpath assessment of the southwest and northeast portions of the parking lot was conducted on July 21, 2009. This assessment was to determine how flow concentrated on the traditional asphalt and how the flow eventually moves onto or across the permeable pavement. This test would help to understand if permeable pavement inserts/retrofits are functional BMPs. The flow path assessment was also repeated on east permeable pavement section on October 21, 2009, in order to determine if cleaning the permeable pavement earlier in the fall had any impact on flows within the parking lot.

4. Well Performance

As discussed above, at the time of the installation of the permeable concrete, a monitoring well was installed in each permeable pavement section. Each monitoring well consisted of a slotted 7.6-cm (3-in) PVC-pipe with a slotted lid. At the time of construction, the wells were installed as a means to gather long-term performance data on the permeable pavement sections. Under the original design, each of the monitoring wells would have been equipped with a Hobo Water Level Logger (water level meter) utilized to measure the amount of water stored. However, prior to the installation of the monitoring equipment, a field study was conducted to evaluate the performance of the permeable pavement and the monitoring wells. The objectives of this field study were:

1. Determine if water leaks from the permeable pavement into the manhole and thus is discharging via the combined sewer and not infiltrating into the ground.
2. Determine if the well in its current placement is representative of water levels in the entire section of permeable pavement.
3. Determine if the installed wells function as planned. The original design assumed that the water level in the wells would rise from the bottom as the permeable pavement, gravel base, and subsoil become saturated.
4. Determine if the well installation is stable and does not change position during storm events.
5. Determine if steady state (a constant infiltration rate) can be achieved in the pavement.

Well performance testing was conducted on July 17, 2009, and repeated on November 12, 2009.

Regional Inventory of BMPs and Monitoring of Rain Gardens

In December 2009, CNT requested a significant modification to the project for 2010, which we considered would have extensive benefits for the State and the region. We proposed to conduct an inventory of the available rain gardens and permeable pavement installations in the Chicago region and to select a number of them for monitoring in 2010.

We considered this new set of tasks because we were encouraged by the results of testing in 2009, where we learned as much or more about the Bellwood gardens and the Roger Park permeable pavement by a few days of controlled testing than from months of storm monitoring. We were also encouraged by the work that has been done at the University of Minnesota, where a procedure using three levels of assessment has been successfully employed and standardized (Asleson et al., 2009). Similar procedures for permeable pavement were also being used by the University of New Hampshire (Anderson et al., 2009).

Inventory of Rain Gardens, Bioswales, and Permeable Pavement in the Chicago Region

To compile the inventory, we surveyed a range of sources to identify as many BMPs as possible in the region. CNT has been involved in 34 rain gardens, bioswales, and permeable pavement facilities during the previous decade and, with Hey, was familiar with many others. We contacted other knowledgeable sources, such as members of the Illinois Association for Floodplain and Stormwater Management, the City of Chicago, the Metropolitan Water Reclamation District (MWRD), the Rain Garden Network, county regulators, watershed organizations, and municipalities to identify other BMPs.

In February 2010, CNT sent out its first survey request to knowledgeable parties in the Chicago region. About 200 email messages were sent requesting recipients to complete the survey (see Appendix A.) The number of responses to the survey was somewhat disappointing, although reminders helped. Far more effective were personal inquiries, networking, and discussions at watershed meetings. All of these methods will continue to be utilized on an ongoing basis to increase the number of green infrastructure features in the inventory. The number of features that were identified during 2010 grew steadily, as is shown in Table 1 below.

As Table 1 indicates, the survey encouraged people to identify green infrastructure features other than just rain gardens and permeable pavement, the features we initially proposed to target. Many of these other features are important and interesting and were thus included in the inventory. We tried to differentiate between native landscapes which people have privately constructed and the native landscapes which are in forest preserves and other public lands. These larger and more natural features are inventoried in other databases and are not replicable by most property owners, so they were not included in this database and map.

About a third of the sites that were identified through the survey turned out not to be suitable for the map. Some were never located in the field, others were inaccessible, and others were not green infrastructure. Currently, the Inventory Map includes 82 sites with another 80 or so awaiting confirmation. We are sure there are hundreds more yet to be located and we project that the numbers will grow rapidly in the future.

Table 1: Inventoried Green Infrastructure Features over Time in 2010

Feature	March 31	June 30	September 30	December 31
Rain Gardens	36	47	57	76
Native Landscapes		37	43	56
Permeable Pavement	8	15	21	32
Bioswales	8	12	17	28
Water Harvesting Systems	4	5	5	6
Stormwater Treatment Trains		4	4	4
Dry Bottom Detention Basins		4	4	4
Green Roofs	2	3	8	11
Infiltration Trenches		1	1	1
Other	24			48
TOTAL	**82**	**128**	**160**	**276**

The distribution of features in the region indicates quite a range in numbers and types, with some areas having only a few and other areas having quite a number of features or BMPs. That range may be accurate in some instances, but it may also indicate that we have not yet made enough contacts in many areas to identify all of the features.

In addition to what is shown in Table 1, the City of Chicago sent CNT two lists, one with over 400 green roof permits that have been issued and the second with 200 green alleys. Unfortunately, the sites will have to be examined to eliminate projects that have not been constructed yet. Most of the green roofs that are not accessible to the public will not be shown on the map, and only a sample of the green alleys will be shown for each part of the City due to lack of time to visit each site and explain how to find it.

CNT also conducted research for the Great Lakes Protection Fund wherein a plan for a web-based registry of green infrastructure implementations was proposed, and this web registry is still a priority at CNT for future development. The ISTC inventory is a first step in that registry. Ultimately, both municipal and private property managers will be able to enter green infrastructure BMPs installed on their property into the registry, including the location, BMP type, size, depth, and other parameters that would affect performance.

The results of the ISTC inventory are displayed as a data layer for the regional maps contained in the Greenmapping website http://greenmapping.org, where maps can be customized by anybody to meet their needs. Figure 3 is a screenshot of the Greenmapping website showing the features. The user can zoom in to a smaller area of interest.

Monitoring Rain Gardens using Visual Assessment, Infiltration Studies, and Synthetic Drawdown Testing

Currently, the most common method for monitoring the performance of BMPs is comprehensive water quantity monitoring involving the determination of the water budget of the BMP using flow meters, data loggers, and other equipment. In previous BMP monitoring efforts conducted in 2007-2009, CNT utilized comprehensive quantity monitoring with success. While valuable data regarding the performance of green infrastructure was obtained through our comprehensive monitoring efforts, several limitations of comprehensive monitoring were observed. These limitations included the cost and effort to setup and maintain such a system and the amount of time required to observe a sufficient number and variety of storm events.

Based on these experiences, CNT and its advisors, including the Fox River Ecosystem Partnership (FREP), designed this project to evaluate the performance of BMPs, specifically rain gardens, using alternative methods that, while being more cost-effective and less time intensive, provided valid and usable data on the performance of BMPs. The three levels of alternative approaches utilized as part of this project included: (1) visual inspection, (2) infiltration rate testing, and (3) synthetic drawdown testing. A fourth level, ongoing monitoring, was not utilized for this work. These methods were originally developed and evaluated by Asleson et al. (2009). The project used the three assessment approaches to evaluate the performance of rain gardens across Northeastern Illinois. The assessment approaches differ in terms of the effort required and results obtained.

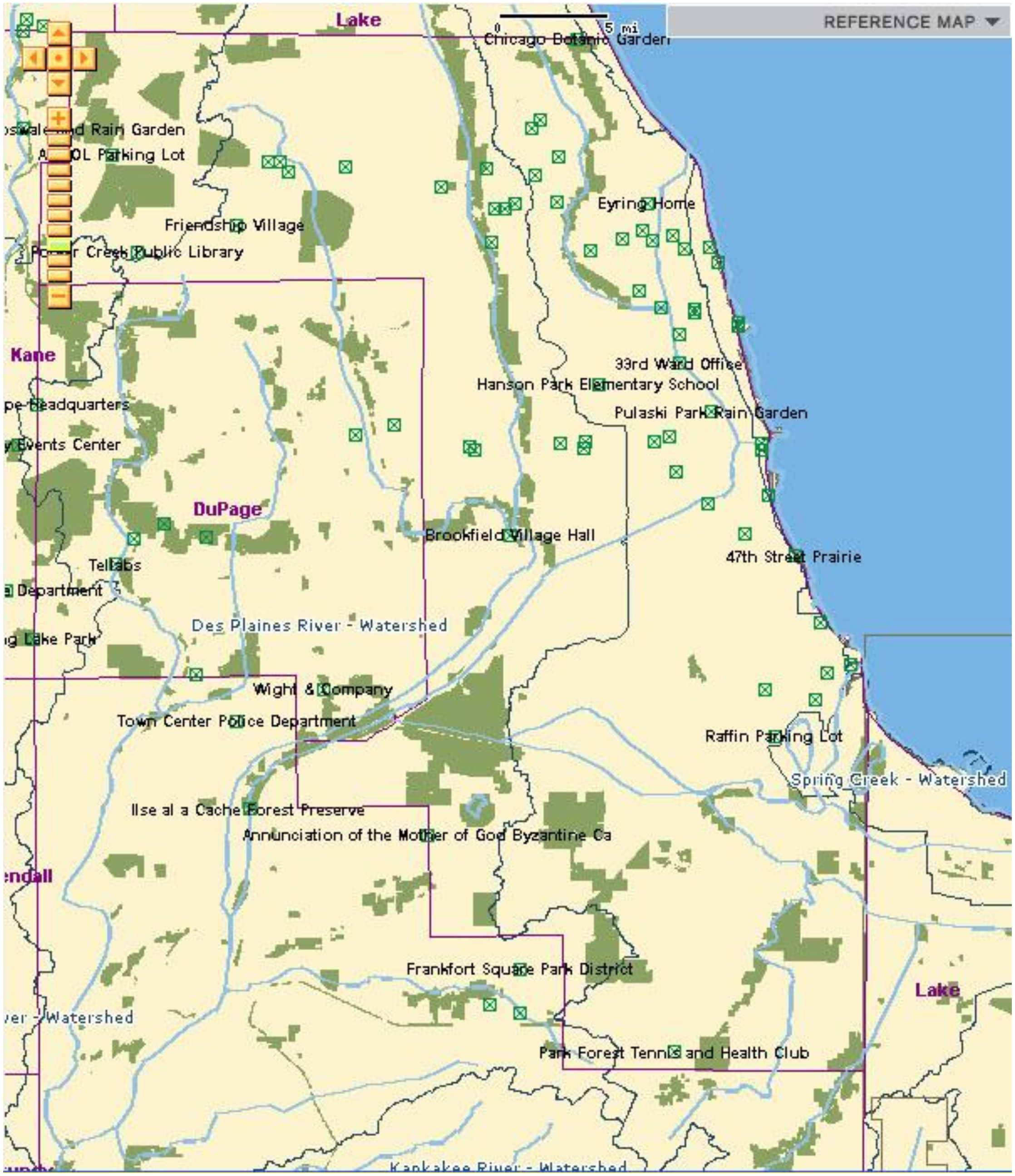

Figure 3: Screenshot of Greenmapping Website

Visual Assessment (Level 1)

Every rain garden and other example of green infrastructure that had been identified prior to snowfalls in December 2010 was visited. We selected approximately 70 of the sites for a detailed visual inspection, including hydrologic problems, vegetation, and soils, as developed by the University of Minnesota (Anderson et al., 2009) and assessed by use of the checklist shown in Appendix B. A typical visit took about 20 to 45 minutes and included taking several photographs. Because of the dispersion of sites throughout the six-county area, visits were planned to either coincide with other work in the area, clustered by area, or were made part of weekend trips.

Infiltration Rate Testing (Level 2)

From the approximately 70 rain gardens that were evaluated using the Level 1 assessment, 15 were selected for infiltration rate testing. These sites were selected based on the permission from the owner/operator, geographic location, and design of the rain garden. It was the goal of the project to select rain gardens that had a variety of runoff sources (roof, street, parking, etc.) and had differing design elements (engineered soils, native soils, sediment forebays, etc.).

The infiltration rate testing of a rain garden includes the use of an infiltrometer to determine near-surface saturated hydraulic conductivity (K_{sat}) at a number of locations throughout the garden. For this project, an infiltrometer based on the Modified Philip-Dunne (MPD) Infiltrometer was used. The MPD Infiltrometer was selected based on the recommendation of Asleson et al. (2009), and the minimal volume of water needed to run the test, the portable size of the device, and the low cost of the device. The infiltrometer was constructed by Hey staff from a PVC pipe with a height of 61 cm (24 in) and an inner diameter of 10.2 cm (4 in). A transparent piezometer tube was attached to the outside of the Infiltrometer next to a measurement tape for making water level readings.

Table 2 includes a summary of the rain gardens evaluated and a short description of the source of runoff and design for each rain garden used. An aerial photograph of each of the 15 rain gardens is contained in Appendix C.

MPD Infiltrometer measurements were taken at a number of locations throughout each rain garden. The number of samples per rain garden was determined by the size of the rain garden (Table 3). The individual testing locations in each rain garden were selected to provide a representative infiltration rate of the various parts of the rain garden (Table 4). In most cases, an infiltration test was conducted near the inlet, center/deepest section, and outlet of each rain garden. In rain gardens where more than three infiltration rate tests were conducted, the additional test sites were selected based on the configuration of the rain garden and included areas such as near dense or sparse vegetation and areas of known ponding. Infiltration testing locations also avoided bushes, trees, shrubs and other vegetation, as well as energy dissipation structures such as rock and concrete. A total of 61 infiltration measurements were collected from the selected 15 rain gardens. Table 4 provides the location of each infiltration measurement.

Table 2: General Description of Level 2 and 3 Assessed Rain Gardens

ID	Rain Garden Name	Size	Level of Assessment	Year Built	Source of Urban Runoff and Design Criteria
1	Crystal Lake, McHenry County, Illinois	800 ft^2	1 and 2	2009	Runoff: Parking lot Design: Native vegetation in native soils
2	Fink Park, Highland Park, Lake County, Illinois	1,200 ft^2	1 and 2	2005	Runoff: Roof and turf grass Design: Native vegetation in native soils
3	Forest Lake Community Center, Lake Zurich, Lake County, Illinois	600 ft^2	1 and 2	not known	Runoff: Roof and parking lot Design: Native vegetation in native soils; soils were tilled prior to planting
4	Fox River Ecosystem Partnership (FREP), St. Charles, Kane County, Illinois	500 ft^2	1 and 2	2009	Runoff: Street and agriculture Design: Native plants in engineered soils
5	Hanson Park Elementary School (East), Chicago, Cook County, Illinois	100 ft^2	1 and 2	2008	Runoff: Roof Design: Native vegetation in native soils
6	Hanson Park Elementary School (West), Chicago, Cook County, Illinois	100 ft^2	1 and 2	2008	Runoff: Roof Design: Native vegetation in native soils
7	Homewood Flossmoor High School, Flossmoor, Cook County, Illinois	2,000 ft^2	1 and 2	not known	Runoff: Roof, asphalt path, turf grass, and tennis courts Design: Native vegetation in native soils
8	McCarty Park, Aurora, Kane County, Illinois	2,400 ft^2	1, 2, and 3	2010	Runoff: Street Design: Native plants in engineered soils
9	Niles Community Garden, Niles, Cook County, Illinois	10,000 ft^2	1, 2, and 3	not known	Runoff: Unpaved parking lot Design: Native plants in engineered soils; outlet pipe is perforated
10	Park Forest Tennis and Health Club, Park Forest, Cook County, Illinois	2,000 ft^2	1 and 2	not known	Runoff: Roof and turf grass Design: Native vegetation in native soils
11	Reinking Road, Pingree Grove, Kane County, Illinois	250 ft^2	1 and 2	2008	Runoff: Street Design: Native plants in engineered soils
12	St. Margaret Mary (East), Chicago, Cook County, Illinois	100 ft^2	1 and 2	2007	Runoff: Roof Design: Native plants in engineered soils
13	St. Margaret Mary (West), Chicago, Cook County, Illinois	100 ft^2	1 and 2	2007	Runoff: Roof Design: Native plants in engineered soils
14	Oregon Avenue, West Dundee, Kane County, Illinois	500 ft^2	1 and 2	2010	Runoff: Street Design: Native plants in engineered soils; has a sediment forebay
15	South End Park, West Dundee, Kane County, Illinois	600 ft^2	1, 2, and 3	2010	Runoff: Street Design: Native plants in engineered soils; has a sediment forebay

Table 3: Number of Infiltration Tests per Rain Garden

Size of Rain Garden	Number of Infiltration Tests
Less than 46 m^2 (500 ft^2)	3
46 m^2 (500 ft^2) to 111 m^2 (1,200 ft^2)	5
Greater than 111 m^2 (1,200 ft^2)	5+ depending on rain garden characteristics

Table 4: Location of Infiltration Tests

ID	Rain Garden Name	Testing Location
1	Crystal Lake, McHenry County, Illinois	Near outfall Near curb cut (center) East side of rain garden
2	Fink Park, Highland Park, Lake County, Illinois	Near inflow Northeast corner (near overflow) Southeast corner (near overflow)
3	Forest Lake Community Center, Lake Zurich, Lake County, Illinois	Near inflow South flow line Near outfall North flow line Northeast corner (area of known concentrated flow)
4	Fox River Ecosystem Partnership (FREP), St. Charles, Kane County, Illinois	Northeast corner (near inflow) Northwest corner (near overflow) Southwest corner (near overflow) Center (southwest quadrant) Southeast corner (near inflow) Center (northwest quadrant)
5	Hanson Park Elementary School (East), Chicago, Cook County, Illinois	Near inflow Center Near overflow
6	Hanson Park Elementary School (West), Chicago, Cook County, Illinois	Near inflow Center Near overflow
7	Homewood Flossmoor High School (HFHS), Flossmoor, Cook County, Illinois	Northwest corner Near center Southeast corner Deepest part of garden (southwest corner) Southwest corner
8	McCarty Park, Aurora, Kane County, Illinois	Near inlet Center of Cell 1 Near cub cut with little vegetation Center of Cell 2 Near curb cut with dense vegetation Near outfall
9	Niles Community Garden (Niles), Niles, Cook County, Illinois	Near inflow East side slope near inflow Center (north of bridge) South of outlet West side slope (south of bridge) Center (south of bridge)
10	Park Forest Tennis and Health Club (PFTHC), Park Forest, Cook County, Illinois	Near overflow Southeast corner of Cell 1 East side of Cell 2 Northeast corner of Cell 3 Center of Cell 3
11	Reinking Road, Pingree Grove, Kane County, Illinois	Center Southeast corner Near inflow (west curb cut)
12	St. Margaret Mary (SMM) (East), Chicago, Cook County, Illinois	Near inflow Center Near overflow
13	St. Margaret Mary (SMM) (West), Chicago, Cook County, Illinois	Near inflow Center Near overflow
14	Oregon Avenue, West Dundee, Kane County, Illinois	Near inflow Center Southeast corner
15	South End Park, West Dundee, Kane County, Illinois	Center Near inflow Southwest corner

Once a location for infiltration testing was selected, all mulch, detached plant material, and/or rock was moved aside and the infiltrometer was pounded into the soil to a depth of 5 cm (2 in) using a rubber mallet. Once installed, the infiltrometer was filled to a depth of 38 cm (15 in) above the ground surface with water. Holes were drilled into the infiltrometer at 38 cm (15 in) above the ground surface to prevent overfilling of the infiltrometer. The water level was recorded manually at various intervals over time. Critical water level versus time readings were taken at 38 cm (15 in), 19 cm (half-full), and 0 cm (empty).

The MPD Infiltrometer works by measuring the time that it takes for a set volume of water to infiltrate into the ground. The factors needed to perform K_{sat} computations include H_0, the initial height of water; H_t, the height of water at time t; L_{max}, the depth of insertion into the soil; and r_1, the radius of the cylinder. A complete description of the background on the computational procedure for K_{sat} is available. In order to facilitate the use of this approach by others, Muñoz-Carpena et al. (2002) prepared a computer program to aid in the computation of K_{sat}. This program is available from his website housed by the University of Florida at http://abe.ufl.edu/carpena/software/pdunne.shtml.

The change in volumetric soil moisture is another factor that is needed when computing K_{sat} using the MPD Infiltrometer. In order to determine volumetric soil moisture changes several measurements are needed. Soil moisture meter readings are taken before and after the infiltration test. Generalized relationships typically provided with soil moisture meters can be used to then relate the soil moisture meter reading to the volumetric soil moisture. In soils that have high sand content, it is recommended that meter calibration be conducted which involves conducting bulk density tests. In reviewing the K_{sat} computation procedure, it was determined that the soil moisture computations were far less important than the time for infiltration measurements. Based on previous tests conducted, it was known that volumetric soil moisture is infrequently less than 10% under normal conditions and rarely greater than 30% (a completely saturated soil with 30% void space). The range for change in soil moisture is not that great (possibly 30% at the highest in a highly permeable and dry soil and 10% at the lowest if a soil was fairly wet when the test started). Because it was known that each test would be started under non-saturated conditions and completed under saturated conditions, it was determined that the change in soil moisture would be estimated to be 20% for all tests. While this approximation led to a slightly less refined test, it was hoped that the merits of this simplification would be proven through the synthetic drawdown tests.

Synthetic Drawdown Testing (Level 3)

From the 15 rain gardens where infiltration capacity testing/infiltration rate testing were conducted, we selected three sites for synthetic drawdown testing during the Spring/Summer 2010 using procedures consistent with those recommended by the University of Minnesota. These BMPs were selected based on location, accessibility to a water source, and size. Synthetic drawdown testing involves the use of a water truck or fire hydrant to fill the rain garden with water and then document the time it takes for the rain garden to completely drain. Table 2 gives details about the three sites: McCarty Park (Site 8), Niles Community Rain Garden (Site 9) and South End Park (Site 15). Appendix C includes an aerial photograph of each site.

Results and Discussion

Bioswale Performance Monitoring at Our Lady Gate of Heaven Parish

The objective of the monitoring at Our Lady Gate of Heaven Parish was to compare the performance of the bioswale during the winter months of 2009/2010 with the performance during the sampling conducted during the fall of 2007 and the spring and summer of 2008. The data collected between December 15, 2009, and February 9, 2010, indicated that the winter conditions did not negatively impact the performance of the bioswale. Figures 4 and 5 show the rise in water levels in the bioswale during two cold-weather rainfall events. The rates of decline in the water surface are an indication of the average infiltration rate within the soils. The infiltration rate of the bioswale was determined to be $2.70\text{x}10^{-4}$ cm/s (0.38 in/hr), which is well within the infiltration rates documented during warmer months of $1.42\text{x}10^{-4}$ to $5.68\text{x}10^{-4}$ cm/s (0.2 to 0.8 in/hr). Additionally, as had been observed during the summer months, the infiltration rate of the swale during the winter months was limited by the infiltration rate of the subsoils and not of the engineered soils or aggregate, indicating that frozen surface conditions do not negatively impact the infiltration rate of the bioswale.

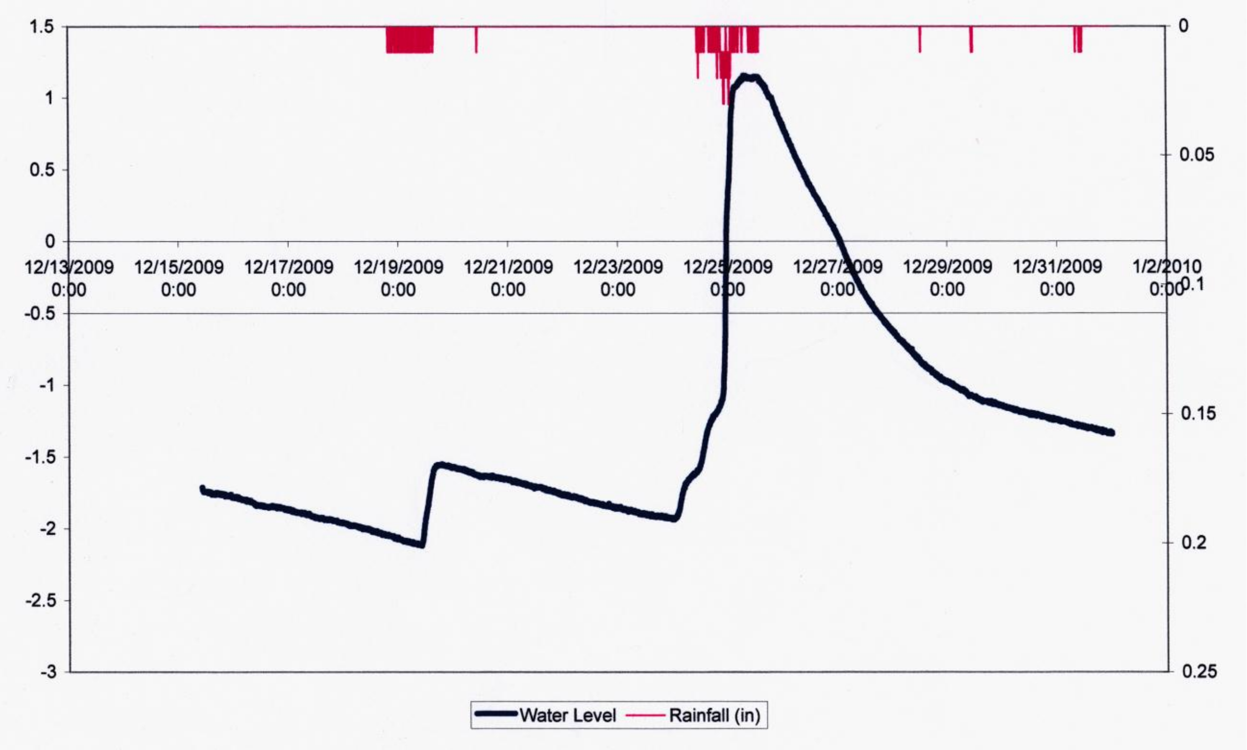

Figure 4: Precipitation and Water Levels in the Bioswale, December 2009

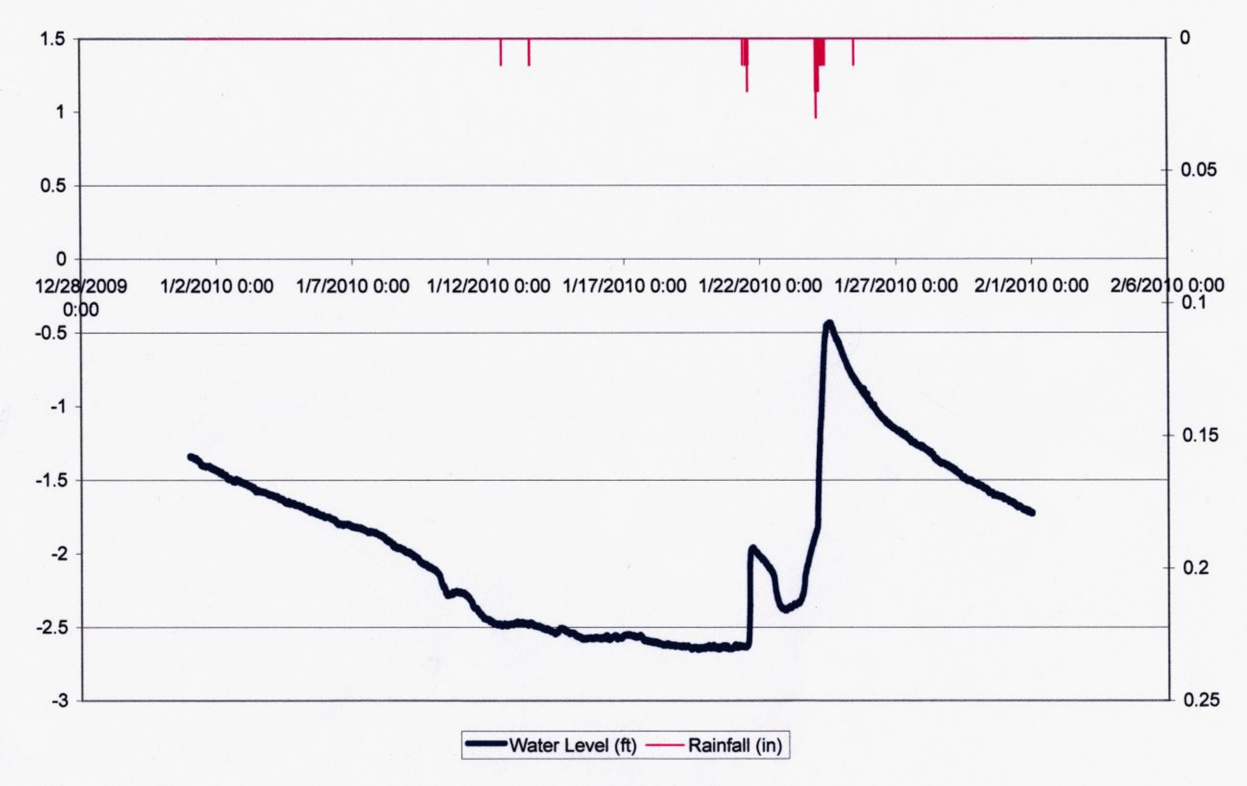

Figure 5: Precipitation and Water Levels in the Bioswale, January 2010

Permeable Concrete Performance Monitoring at St. Margaret Mary Parish

Infiltration Testing

In order to determine the infiltration rate of the permeable concrete, on July 21, 2009, and October 21, 2009, infiltration testing was conducted using a single-ringed infiltrometer on each of the two permeable concrete sections. The single-ringed infiltrometer was constructed from a 3.5-gal paint bucket. In order to construct the infiltrometer, the bottom of the bucket was removed using a utility knife. The inside of the bucket was then labeled with 2.54-cm (1-in) increments.

On July 21, 2009, the infiltrometer was positioned upside down in the southwest corner of the east permeable concrete section and in the northeast corner of the west permeable concrete section. At both locations, the infiltrometer was sealed to the pavement using plumber's putty (Figure 6). The infiltration rate was to be determined by filling the infiltrometer with 15 cm (6 in) of water and documenting the time it took for 10.2 cm (4 in) of water to infiltrate into the pavement (drawing down of water level from 15.2 cm to 5.1 cm [6 to 2 in]). The infiltrometer would then be re-filled with 15.2 cm (6 in) of water and allowed to drain down to 5.1 cm (2 in) for a second time and the time documented. This step was to be repeated until the time to draw down from 15.2 to 5.1 cm (6 to 2 in) was constant (indicating steady state infiltration have been achieved). The testing water was City of Chicago water obtained from St. Margaret Mary's Activity Center.

Figure 6: Infiltrometer at Permeable Pavement at St. Margaret Mary Parish

However, during the testing, the methods were altered because the infiltration rate was significantly less than anticipated. As planned, the infiltrometer was filled to 15.2 cm (6 in) with water. After three hours, the water in the infiltrometer in the east section had only drawn down to 7 cm (2.75 in) and after two hours, the water in the infiltrometer in west section had only drawn down to 8.6 cm (3.375 in). As such, the test in the east section was stopped after three hours and the test in the west section was stopped after two hours. Using these results, the infiltration rate of the east permeable pavement section was determined to be 7.7×10^{-4} cm/s (1.08 in/hr) and the west permeable concrete section was determined to be 9.3×10^{-4} cm/s (1.31 in/hr). These infiltration rates were significantly less than what is expected for permeable concrete. For example, infiltration testing conducted on the permeable concrete green alley located at 10300 South Avenue G in Chicago indicated infiltration rates of 0.112 cm/s to 0.305 cm/s (157.9 in/hr to 429.3 in/hr). As such, it was recommended that the permeable concrete sections at St. Margaret Mary be cleaned prior to future infiltration testing. The permeable concrete sections were power washed in late summer 2009.

Following the cleaning of the permeable concrete sections, new infiltration testing was conducted on October 21, 2009. The infiltrometer was placed in the west side of the east permeable concrete section and the east side of the west permeable concrete section. At both locations, the infiltrometer was sealed to the pavement using plumber’s putty. The infiltration rate was determined by filling the infiltrometer with 22.9 cm (9 in) of water and documenting the time it took for 10.2 cm (4 in) of water to infiltrate into the pavement (drawing down the water level from 22.9 cm to 12.7 cm (9 to 5 in). The infiltrometer was then re-filled with 22.9 cm (9 in) of water and allowed to drain down to 12.7 cm (5 in) for a second time and the time documented. This step was repeated until the time to draw down from 22.9 cm to 12.7 cm (9 to 5 in) was constant. The increase in the depth of water from 15.2 cm (6 in) to 22.9 cm (9 in) between the first test on July 21, 2009, and the second test on October 21, 2009, was made so that the water depth on the infiltrometer could more easily be read by the field staff. The testing water was City of Chicago water obtained from St. Margaret Mary’s Activity Center.

The infiltration rates recorded throughout the experiment are presented below in Table 5 for the east pavement section and Table 6 for the west pavement section. The infiltration rates for the east permeable pavement section ranged from $3.25x10^{-3}$ to $5.62x10^{-2}$ cm/s (4.58 to 79.21 in/hr) with an average infiltration rate of $1.96x10^{-2}$ cm/s (27.58 in/hr). The infiltration rates for the west permeable pavement section ranged from $3.53x10^{-3}$ to $3.75x10^{-2}$ cm/s (4.97 to 52.75 in/hr) with an average infiltration rate of $1.37x10^{-2}$ cm/s (19.3 in/hr). The infiltration rates measured after cleaning were significantly higher than those measured before the pavement was cleaned on July 21, 2009.

Surface Infiltration Capacity Testing

The surface infiltration capacity (SIC) testing differs from the infiltration testing previously conducted at the site because it is a modified falling head surface infiltration test (SIT). SIC testing was conducted by placing a 30.5-cm (12-in) infiltrometer constructed of a plastic pipe onto the pavement and filling the infiltrometer with 13.2 L (5 gal) of water and documenting the time it takes for the 13.2 L (5 gal) to infiltrate into the pavement.

Table 5: Infiltration Rates for the East Permeable Pavement Section – October 21, 2009

Trial	cm (in)	Time (min)	Time (hr)	Cumulative Time (hr)	Infiltration Rate cm/s (in/hr)
1	10.16 (4)	3.03	0.05	0.05	$5.62x10^{-2}$ (79.21)
2	10.16 (4)	6.95	0.12	0.17	$2.45x10^{-2}$ (34.53)
3	10.16 (4)	11.41	0.19	0.36	$1.45x10^{-2}$ (21.01)
4	10.16 (4)	14.80	0.25	0.61	$1.15x10^{-2}$ (16.22)
5	10.16 (4)	24.15	0.40	1.01	$7.06x10^{-3}$ (9.94)
6	5.08 (2)	26.20	0.44	1.45	$3.25x10^{-3}$ (4.58)
Average Infiltration Rate					**$1.96x10^{-2}$ (27.58)**

Table 6: Infiltration Rates for the West Permeable Pavement Section – October 21, 2009

Trial	cm (in)	Time (min)	Time (hr)	Cumulative Time (hr)	Infiltration Rate cm/s (in/hr)
1	10.16 (4)	4.55	0.08	0.08	$3.75x10^{-2}$ (52.75)
2	10.16 (4)	9.40	0.16	0.23	$1.81x10^{-2}$ (25.53)
3	10.16 (4)	16.02	0.27	0.50	$1.06x10^{-2}$ (14.98)
4	10.16 (4)	23.23	0.39	0.89	$7.33x10^{-3}$ (10.33)
5	10.16 (4)	33.21	0.55	1.44	$5.13x10^{-3}$ (27.23)
6	7.62 (3)	36.25	0.60	2.04	$3.53x10^{-3}$ (4.97)
Average Infiltration Rate					**$1.37x10^{-2}$ (19.30)**

The infiltrometer was sealed to the pavement using plumber's putty. Testing water was City of Chicago water obtained from St. Margaret Mary's Activity Center. Each permeable pavement section was tested at four locations. Locations were distributed throughout the pavement sections in order to see if the SIC varied across the pavements and if the proximity to the storm drain and/or non-permeable asphalt had an effect on the pavement's SIC. A fifth location was also tested on the west pavement in an area where the permeable pavement appeared distressed.

The SIC rates recorded on November 12, 2009, and March 18, 2010, are presented in Table 7 for the east pavement section and Table 8 for the west pavement section. Minor leaks were observed during the testing at Locations E1 and W2 on November 12, 2009, and at Locations E4 and W4 on March 18, 2010. Upon discovery, the leaks were stopped with the addition of plumber's putty.

On November 12, 2009, the SIC rates for the east permeable pavement section ranged from 2.36×10^{-2} to 4.81×10^{-2} cm/s (33.20 to 67.79 in/hr) with an average infiltration rate of 3.32×10^{-2} cm/s (46.75 in/hr). For the west section, they ranged from 3.75×10^{-2} to 6.27×10^{-2} cm/s (52.81 to 88.25 in/hr) with an average infiltration rate of 4.90×10^{-2} cm/s (68.99 in/hr) (not including the SIC observed on the distressed section of pavement).

On March 18, 2010, the SIC rates for the east permeable pavement section ranged from 4.27×10^{-3} to 4.53×10^{-2} cm/s (6.01 to 63.75 in/hr) with an average infiltration rate of 2.45×10^{-2} (34.51 in/hr). For the west section, SIC rates ranged from 7.40×10^{-3} to 4.53×10^{-2} cm/s (10.42 to 63.80 in/hr) with an average infiltration rate of 3.00×10^{-2} (42.19 in/hr). There was a 26.18% decrease in average infiltration rate in the east permeable pavement section and there was a 38.84% decrease in average infiltration rate in the west permeable pavement section between November 12, 2009, and March 18, 2010.

As noted above, an area of distressed pavement was observed in the west permeable pavement section. The distressed area ran from east to west through the center of the pavement square. Based on the location of the distressed area and the slope of the parking lot, it appears that the distressed area receives the most concentrated flows during storm events. In this area, the SIC rates of 4.04×10^{-3} cm/s (5.70 in/hr) were found to be significantly lower than the rates in other areas tested in the west permeable pavement section. It was the opinion of Hey and Associates that the lower SIC rates were caused by debris lodged into the pavement and not by the actual damage to the surface of the parking lot.

Table 7: SIC Rates for the East Permeable Pavement Section – November 12, 2009 & March 18, 2010

Site ID Number	Location*	11/12/2009		3/18/2010		% Change
		Time (sec)	Surface Infiltration Capacity cm/s (in/hr)	Time (sec)	Surface Infiltration Capacity cm/s (in/hr)	
1E	Southwest corner – 116 cm (45.5 in) from south edge of pavement and 122 cm (48 in) from west edge of pavement	542	4.81x10^{-2} (67.79)	1506	1.73x10^{-2} (24.41)	-64.0
2E	Southeast corner – 110 cm (43.25 in) from south edge of pavement and 94 cm (37 in) from east edge of pavement	777	3.36x10^{-2} (47.35)	838	3.11x10^{-2} (43.87)	-7.34
3E	Northeast corner – 41 cm (16.0 in) from north edge of pavement and 38 cm (15 in) from east edge of pavement	952	2.74x10^{-2} (38.64)	6120	4.27x10^{-3} (6.01)	-84.45
4E	Northwest corner – 157 cm (61.75 in) from north edge of pavement and 188 cm (74 in) from west edge of pavement	1107	2.36x10^{-2} (33.20)	577	4.53x10^{-2} (63.75)	91.99
	Average SIC		**3.32x10^{-2} (46.75)**		**2.45x10^{-2} (34.51)**	**-26.18**

* To center of infiltrometer

Table 8: SIC Rates for the West Permeable Pavement Section – November 12, 2009 & March 18, 2010

Site ID Number	Location*	11/12/2009		3/18/2010		% Change
		Time (sec)	Surface Infiltration Capacity cm/s (in/hr)	Time (sec)	Surface Infiltration Capacity cm/s (in/hr)	
1W	Southwest corner – 87 cm (34.25 in) from south edge of pavement and 89 cm (35 in) from west edge of pavement	467	5.59x10^{-2} (78.72)	3529	7.40x10^{-3} (10.42)	-86.77
2W	Southeast corner – 110 cm (43.25 in) from south edge of pavement and 94 cm (37 in) from east edge of pavement	417	6.27x10^{-2} (88.25)	576	4.53x10^{-2} (63.80)	-27.7
3W	Northeast corner – 41 cm (16.0 in) from north edge of pavement and 38 cm (15 in) from east edge of pavement	654	3.99x10^{-2} (56.18)	648	4.03x10^{-3} (56.73)	0.97
4W	Northwest corner – 157 cm (61.75 in) from north edge of pavement and 188 cm (74 in) from west edge of pavement	696	3.75x10^{-2} (52.81)	972	2.69x10^{-2} (37.82)	-28.38
	Average SIC		**4.90x10^{-2} (68.99)**		**3.00x10^{-2} (42.19)**	**-38.84**
5W	Distressed area - 224 cm (88.25 in) from north edge of pavement and 96 cm (38 in) from west edge of pavement**	3610	4.04x10^{-3} (5.7)	NA	NA	NA

* To center of infiltrometer

** Test conducted with 10.6 L (2.8 gal) of water

Flowpath Assessment

A 50-ft perforated sprinkler hose positioned along the edge of the parking lot served as the water source for the flowpath assessments conducted on July 21, 2009, and October 21, 2009. A hose was utilized instead of an actual storm event, as the hose simulated rainfall without wetting the entire parking lot surface. Therefore, Hey was able to determine the flow patterns of the parking lot. If the entire parking lot was wet, as it would be in a storm, it would have been difficult to determine isolated flow lines in the parking lot.

Prior to positioning the sprinkler hose for the flowpath assessment, the flow rate of the hose was determined by placing the hose in a 58.8-L (20-gal) plastic container and timing how long it took to fill up the container. On July 21, 2009, the flow rate of the hose was estimated at 0.13 L/s (2.06 gal/min) and the flow rate was estimated at 0.091 L/s (1.44 gal/min) on October 21, 2009.

July 21, 2009 - Southwest portion of the parking lot

The 15-m (50-ft) sprinkler hose was placed along the southern edge of the west side of the parking lot approximately 1.2 m (4 ft) from the curb. Photographs and field notes were taken as the water flowed towards the permeable pavement. Significant events are documented in Table 9.

Table 9: Flowpath Assessment Significant Events for the Southwest Portion of the Parking Lot (0.13 L/s) – July 21, 2009

Time (minutes after the start of the assessment) (min:sec)	Event
0:00	Hose, with a flow rate of 0.13 L/s is placed along the southern edge of the west side of the parking lot about 1.2 m (4 ft) from the southern curb.
0:00-5:00	Flow concentrates along the cracks in the pavement.
5:55	Water begins to pool along the southern edge of the west permeable pavement section near the center of the south side of the section. The permeable pavement is slightly higher in elevation than the adjacent asphalt pavement.
8:20	Water begins to flow across the southern edge of the west permeable pavement section.
8:20-28:11	Water, originating from the south side of the pavement, flows across the permeable pavement towards the manhole (but does not flow into the manhole). Water is flowing in a concentrated flow path that is approximately 15 to 20 cm (6 to 8 in) in width.
9:40	Water begins to pool along the eastern edge of the west permeable pavement section near the center of the east side of the section.
28:12	Water, in a concentrated flow line from the south, flows into manhole. The concentrated flow path of water from the south edge into the manhole is approximately 15 to 20 cm (6 to 8 in) in width.
28:12-120:00	Water, in a concentrated flow line from the south, continues to flow into the manhole. Some capillary spreading around the flow line across the permeable pavement is observed.
120:00	Test is stopped. Water, in a concentrated flow line from the south, continues to flow into the manhole. Water is pooled along the eastern side of the west permeable pavement section. No water was observed along the north and west sides of the west permeable pavement section. Additionally, no water was observed on the east permeable pavement section. No water was observed in the monitoring well.

July 21, 2009 - Northeast Portion of the Parking Lot

The 15-m (50-ft) sprinkler hose was placed along the northern edge of the parking lot approximately 1.2 m (4 ft) from the curb. The flow rate of the hose was measured to be 0.13 L/s (2.06 gal/min). The hose was positioned a bit closer to the center of the parking lot than in the assessment of the southwest section of the parking lot. The change was made in order to locate the tributary area divide between the two permeable pavement sections. Photographs and field notes were taken as the water flowed towards the permeable pavement. Significant events are documented in Table 10.

October 21, 2009 - Northeast Portion of the Parking Lot

The 15-m (50-ft) sprinkler hose was placed along the northern edge of the parking lot approximately 1.2 m (4 ft) from the curb in close proximity to the hose placement in the July 21, 2009 test. The flow rate of the hose was measured to be 0.091 L/s (1.44 gal/min). Photographs and field notes were taken as the water flowed towards the permeable pavement. Significant events are documented in Table 11.

Table 10: Flowpath Assessment Significant Events for the Northeast Portion of the Parking Lot (0.13 L/s) – July, 21, 2009

Time (minutes after the start of the assessment) (min:sec)	Event
0:00	Hose is placed on the east side of the parking lot approximately 1.2 m from the northern curb.
0:00-3:34	Flow concentrates along the cracks in the pavement.
3:35	Water begins to pool along the northern edge of the east permeable pavement section.
3:38	Water begins to pool along the east side of the west permeable pavement section.
3:35-97:00	Water, originating from the north side of the east permeable pavement section, flows across the pavement towards the manhole. Water is not flowing in a concentrated flow line as it did on the west permeable pavement section.
112:00	Water flows into manhole.
120:00	Test is stopped. Water, from the north, continues to flow into the manhole. Water is pooled along the western side of the east permeable pavement section. No water was observed along the south and east sides of the east permeable pavement section. No water was observed in the monitoring well.

Table 11: Flowpath Assessment Significant Events for the Northeast Portion of the Parking Lot (0.091 L/s) – October 21, 2009

Time (minutes after the start of the assessment) (min:sec)	Event
0:00	Hose is placed on the east side of the parking lot approximately 1.2 m (4 ft) from the northern curb.
0:00-1:21	Flow concentrates along the cracks in the pavement.
1:21	Water begins to pool along the northern edge of the east permeable pavement section.
2:48-68:00	Water, originating from the north, west, and east sides of the east permeable pavement section, slowly moves across the permeable pavement. Water is infiltrating into the pavement. No water flows into the storm drain.
68:00	The sprinkler hose is detached from the supply hose and the supply hose is allowed to flow directly onto to the southeast corner of the permeable pavement.
81:30	Water flows into manhole.
85:07	Test is stopped.

When the visible results of the October 21, 2009, flow path assessment experiment are compared with the visual results of the July 21, 2009, flow path assessment experiment, it appears that the cleaning of the permeable pavement sections that was conducted between July and October increased the infiltration capacity of the permeable pavement.

Monitoring Well Performance Testing

Monitoring well performance testing was conducted on July 17, 2009 and November 12, 2009. The monitoring well performance testing was conducted by placing a running hose at the edge of the permeable pavement section at the edge closest to the well. The time required to reach the following conditions was then recorded:

- Leaking in to the manhole below the surface
- Surface overflow into the manhole
- Direct flow into the well

Prior to the placement of the hose, the flow rate of the hose was determined by placing the hose in a 19-L (5-gal) plastic bucket and timing how long it took to fill up the bucket.

July 17, 2009 – Monitoring Well Performance Testing

The hose was placed on the west side of the east permeable pavement section parallel with the monitoring well. The flow rate of the hose was determined to be 0.45 L/s (7.14 gal/min). The results are described in Table 12.

Considering how quickly surface flow was able to flow directly into the manhole, it was determined that the flow of the hose exceeded the permeability of the pavement. As such, the test was redesigned in order to reduce the flow rate of the hose. As part of the redesign, the flow from the single hose was split into four 4.6-m (15-ft) hoses using a one-to-four hose metal manifold. The flow rate of the new system was then measured by placing the four hoses in a 19-L (5-gal) plastic bucket and timing how long it took to fill up the bucket. The flow of the four hoses was estimated at 0.205 L/s (3.25 gal/min) to 0.051 L/s (0.81 gal/min) per hose.

One of the four hoses was then placed on each of the four corners of the west permeable pavement section. The west side of the parking lot was utilized to allow time for the east side to dry. The configuration of the hoses is shown in Figure 7. Significant events are documented in Table 13.

Table 12: Well Performance - Significant Events for the East Permeable Pavement Section (0.45 L/s) – July 17, 2009

Time (minutes after the start of the assessment) (min:sec)	Event
0:08	Surface flow of water into monitoring port was observed (i.e., well was filled from the surface flow and not from the bottom of the well as expected).
0:48	Surface flow of water into manhole observed.
17:48	Tested stopped. No water was observed to be leaking from the below the pavement surface into the manhole.

Figure 7: Configuration of Hoses on West Permeable Pavement Section

Table 13: Well Performance - Significant Events for the West Permeable Pavement Section (0.205 L/s) – July 17, 2009

Time (minutes after the start of the assessment) (min:sec)	**Event**
1:15	Surface flow of water from the southwest corner of the west permeable pavement section into manhole observed.
2:11	Surface flow of water from the northwest corner of the west permeable pavement section into manhole observed.
4:19	Surface flow of water from the northeast corner of west permeable pavement section into manhole observed.*
5:02	Surface flow of water into monitoring port observed (i.e., well was filled from the surface flow and not from the bottom of the well as expected).
14:16	Surface flow fills monitoring port. However, the inside of the monitoring well appeared dry.
15:06	Water from the monitoring port fills the monitoring well.
16:35	Monitoring port and well are completely filled with water.
45:21	Tested stopped. No water was observed to be leaking from the below the pavement surface into the manhole.

* Surface flow from the southeast corner of the west permeable pavement section does not drain to the manhole. It flows along the edge of the east side of the west permeable pavement section to the northeast corner where it joins the flow originating in the northeast corner.

The results indicated that the monitoring wells were not functioning as planned. The wells were checked to see if the well slots had been blocked by debris. Filling the wells with water indicated that the well slots were not blocked and the wells were in good condition. However, as a preventative measure, the well slots were cleaned with a toothbrush and the wells were wrapped in gauze to prevent debris from clogging the well slots.

The field test also indicated that the monitoring port and wells were filled by surface runoff. The original design of the monitoring effort required that the wells be filled from the bottom as the permeable pavement, gravel base, and subsoil become saturated. As such, the slots in the housing covers were blocked with a sealant to seal the surface wells and prevent the surface inflow of water into the well.

The four hoses were then placed on the east permeable pavement section. Additionally, plastic gloves filled with water were placed on the downstream side of the hoses in order to serve as check dams and diffuse the flow from the hoses. The east side of the parking lot was utilized to allow time for the west side to dry. The results are described in Table 14.

As noted in Table 14, once the well covers were sealed, the well cap was forced off the monitoring port from the pressure beneath it. This indicated that the ports were capable of allowing subsurface inflow but were not so permeable that they remained at atmospheric pressure. If the ports and water level meters are to be effective, a careful balancing act of preventing surface inflow from entering the ports and allowing for pressure equalization will be needed. At the time of the experiment, a procedure to maintain pressure equalization was unknown and the ability to use the monitoring ports for the long-term performance monitoring was not feasible.

November 12, 2009 – Monitoring Well Performance Testing

The monitoring well performance test was repeated on November 12, 2009, on the east permeable pavement section to determine if there was potential to reconfigure the wells so that they could be utilized for long-term performance monitoring. The water source for the well performance experiment was a single hose split into four 4.6-m (15-ft) hoses using a one-to-four hose metal manifold. Due to the length of the supply hose, only two of the four hoses were turned on and used during the well performance assessment. Prior to the placement of the hose, the flow rate of the hose was determined by placing the two hoses in a 75-L (20-gal) plastic bucket and timing how long it took to fill up the bucket. The flow of the hose was estimated at 0.478 L/s (7.58 gal/min).

Based on what was learned in the July 17, 2009, experiments, in order for the monitoring ports to function as planned they would need to be vented to allow for pressure equalization and blocked to prevent water from flowing into the monitoring well from the surface. In order to achieve these two conditions, the sealed lid was vented and surface flow was blocked from entering the well by placing a six-inch metal pipe around the top of the well. The metal pipe was sealed to the pavement using plumber’s putty. The results are described in Table 15.

As detailed in Table 15, with a vented lid and a barrier to prevent surface flow from entering the ports, the monitoring ports functioned as designed. However, because the parking lot is frequently used by vehicles, it is impractical and unsafe to leave a barrier around the monitoring ports. As such, it was determined that using the monitoring wells for long-term performance monitoring in their current configuration was not feasible.

Table 14: Well Performance - Significant Events for the East Permeable Pavement section (0.205 L/s) – November 12, 2009

Time (minutes after the start of the assessment) (min:sec)	Event
1:00	Surface flow of water from the southeast corner of the east permeable pavement section into manhole observed.
2:00	Surface flow of water from the northeast corner of the east permeable pavement section into manhole observed.
12:00	Surface flow reaches the sealed monitoring port.
18:00	The cap of the monitoring port is forced off by water from within the port.
27:00	Tested stopped. No water was observed to be leaking from the below the pavement surface into the manhole.

Table 15: Well Performance - Significant Events for the East Permeable Pavement Section (0.478 L/s) – November 12, 2009

Time (minutes after the start of the assessment) (min:sec)	Event
0:00	Hose is placed on the southeast corner of the east permeable pavement section.
0:57	Water originating from the southeast corner of the pavement section enters the storm drain.
4:45	Water is observed in the bottom of the monitoring well.
4:45-39:00	Water begins to slowly fill the monitoring well from the bottom up indicating that the wells are functioning as designed.
7:59	Water is no longer flowing into the storm drain. After an initial first flush to remove debris from the pavement, water appears to be infiltrating in to the pavement.
32:00	Water begins to leak into storm drain through the walls of the catchment basin and not from the surface of the parking lot.
39:00	Test is stopped.

Inventory of Rain Gardens, Bioswales, and Permeable Pavement in the Chicago Region

The Greenmapping Website

A data layer displaying these sites has been prepared for the Greenmapping website, http://greenmapping.org, so that anyone can learn where they are and visit them to gain information that can lead to their replication throughout the region. The map with the 82 known sites can be seen on the website above by selecting “Interactive Map” and then “Green Infrastructure Demonstration Sites” (see Figure 3 for screenshot of the map). By clicking on a site, the user has access to three items, when available, including an address, a brief description (with link), and a photograph.

The database, which we plan to continue to update, will include all of the known sites, not just those shown on the map, so that the cumulative impact of all sites can be estimated when desired. We also plan to continue to employ direct communications as well as the survey instrument to locate additional sites.

Monitoring Rain Gardens in Chicago Region

Visual Assessment (Level 1)

The results of the visual assessment of approximately 70 rain gardens, bioswales, and other features that contain native vegetation and are designed to infiltrate stormwater can be summarized as follows:

1. The age of most features was not readily available, but age may not be a major factor after a year or two.
2. Our experience was that after a day or so there was little or no standing water, unless the features were clearly designed to retain a permanent water level. It was not essential to know details about recent rainfall.
3. None appeared to have saturated soils unless there was supposed to be standing water.
4. None of the soils appeared to be compacted. (We did not examine the soil profile.)
5. Many of the features did not have well-defined inlet structures, and very few had inlet structures that indicated malfunctions. A few had minor erosion or sedimentation but not enough to affect performance. (As discussed later, some had infiltration patterns that indicated sedimentation at the inlet, but these were seldom visible.)
6. No features showed signs of water pollution.
7. Vegetation was widely divergent. All of the features contained, by our definition, native plants but the distribution of native and other plants was not determined. Some features were well maintained with healthy and primarily native plants. Others needed maintenance. Only a small fraction had inadequate plant coverage; only recently planted vegetation had inadequate plant coverage. The time of year obviously affects the distribution of species that are predominant and, therefore, the look of the feature.
8. Even the most poorly maintained features looked as if they could be restored with routine weeding (for smaller and urban sites) or a prescribed burn (for larger sites).
9. Bank erosion was identified in very few sites.

Infiltration Rate Testing (Level 2)

Sixty-one MPD infiltration tests were conducted in the 15 rain gardens as detailed in Tables 16A and 16B and Table 17. The locations of the infiltration tests for each rain garden are shown on the aerial photographs in Appendix C.

The time required for each individual MPD test to be completed ranged from 30 s (Niles- inflow) to 28,443 s (7 hr 54 min) (Fink Park – southeast corner) with an average time of 2,607 s (34 min 27 s). Ninety-two percent (92%) of the MPD tests were completed in less than one hour. Only one of the MPD tests was terminated (Fink Park – inlet) due to minimal change in water level over a three-hour period.

K_{sat} values were calculated using the data obtained from the MPD tests using the methods outlined in the Methods and Analysis section. It should be noted that K_{sat} values were not calculated for six of the sampling locations. A K_{sat} value was unable to be calculated for Fink Park – inlet as the MPD test was terminated due to low infiltration rates prior to obtaining 19 cm (half-full), and 0 cm (empty) water level versus time readings. Additionally, five MPD tests had infiltration rates that were greater from half-empty to empty than from full to half-empty. MPD infiltration rates that are quicker from half-empty to empty than from full to half-full do not meet the requirements of the data fitting procedure used to determine K_{sat} and thus K_{sat} values for these five samples could not be calculated.

There are a number of possible reasons that the infiltration rates could increase over the course of the test instead of decrease as expected. These reasons include (1) having the seal between the infiltrometer and the ground become compromised during the test allowing water to leak at the seal instead of being infiltrate and (2) human error in the timing of the test due to the quickness of the observed infiltration rates. Due to the data fitting procedure used to calculate K_{sat} values, all data points where the infiltration rates were greater from half-empty to empty than from full to half-empty could not have K_{sat} values calculated and the results of these tests are not included in this report.

The calculated K_{sat} values for the 55 valid tests ranged from $2.69x10^{-4}$ to $9.08x10^{-2}$ cm/s (0.42 to 127.9 in/hr) with a mean K_{sat} of $1.81x10^{-2}$ cm/s (25.5 in/hr). Tables 16A and 16B contain the K_{sat} values for each of the 15 sites. Statistics for measured K_{sat} values by site are presented in Tables 16A and 16B and for the combined total in Table 17. The average, minimum, and maximum K_{sat} values for each site are illustrated in Figure 8.

Table 16A: Statistics for Measured K_{sat} Values by Site for the First Seven Sites

Statistical Parameter	**Crystal Lake**	**Fink Park**	**FREP**	**Forest Lake Commun. Center**	**Hanson Park**		**HFHS**	**McCarty Park**
					East	**West**		
Number of Measurements	2	1	6	5	3	3	5	6
Mean cm/s (in/hr)	$2.48x10^{-2}$ (34.92)	$4.86x10^{-4}$ (0.68)	$4.19x10^{-3}$ (5.90)	$1.42x10^{-2}$ (20.0)	$2.71x10^{-3}$ (3.82)	$2.39x10^{-2}$ (33.66)	$1.62x10^{-2}$ (22.82)	$1.71x10^{-2}$ (24.08)
Geometric Mean cm/s (in/hr)	$2.47x10^{-2}$ (34.78)	$4.86x10^{-4}$ (0.68)	$3.30x10^{-3}$ (4.65)	$1.26x10^{-2}$ (17.75)	$2.57x10^{-3}$ (3.62)	$7.98x10^{-3}$ (11.24)	$3.02x10^{-3}$ (4.25)	$1.52x10^{-2}$ (21.41)
Median cm/s (in/hr)	$2.48x10^{-2}$ (34.92)	$4.86x10^{-4}$ (0.68)	$4.28x10^{-3}$ (6.03)	$1.32x10^{-2}$ (18.59)	$2.05x10^{-3}$ (2.89)	$4.23x10^{-3}$ (5.96)	$3.19x10^{-3}$ (4.49)	$1.89x10^{-2}$ (26.62)
Standard Deviation cm/s (in/hr)			$2.55x10^{-3}$ (3.59)	$6.99x10^{-3}$ (9.58)	$1.16x10^{-3}$ (1.63)	$3.62x10^{-2}$ (50.99)	$2.57x10^{-2}$ (36.20)	$7.18x10^{-3}$ (10.11)
Coefficient of Variation %			60.80	49.38	42.66	151.37	158.89	42.02
Minimum cm/s (in/hr)	$2.28x10^{-2}$ (32.11)	$4.86x10^{-4}$ (0.68)	$7.15x10^{-4}$ (1.01)	$5.35x10^{-3}$ (7.54)	$2.04x10^{-3}$ (2.87)	$1.83x10^{-3}$ (2.58)	$2.69x10^{-4}$ (0.38)	$4.85x10^{-3}$ (6.83)
Maximum cm/s (in/hr)	$2.68x10^{-2}$ (37.75)	$4.86x10^{-4}$ (0.68)	$7.86x10^{-3}$ (11.10)	$2.44x10^{-2}$ (34.37)	$4.05x10^{-3}$ (5.70)	$6.57x10^{-2}$ (92.50)	$6.06x10^{-2}$ (85.40)	$2.44x10^{-2}$ (34.37)

Table 16B: Statistics for Measured K_{sat} Values by Site for the Last Seven Sites

Statistical Parameter	Niles	PFTHC	Reinking Road	SMM		Oregon Avenue	South End Park
				East	West		
Number of Measurements	5	5	3	3	3	2	3
Mean cm/s (in/hr)	2.73×10^{-2} (38.45)	1.02×10^{-2} (14.37)	1.38×10^{-2} (19.44)	2.46×10^{-2} (34.65)	2.74×10^{-3} (3.86)	8.36×10^{-2} (117.7)	3.18×10^{-2} (45.43)
Geometric Mean cm/s (in/hr)	1.21×10^{-2} (17.04)	9.67×10^{-3} (13.62)	2.98×10^{-3} (4.20)	1.37×10^{-2} (19.26)	1.25×10^{-3} (1.76)	8.35×10^{-2} (117.6)	2.60×10^{-2} (36.62)
Median cm/s (in/hr)	1.68×10^{-2} (23.66)	7.67×10^{-3} (10.80)	1.19×10^{-3} (1.68)	7.80×10^{-3} (10.99)	6.78×10^{-4} (0.95)	8.36×10^{-2} (117.7)	2.44×10^{-2} (34.37)
Standard Deviation cm/s (in/hr)	3.66×10^{-2} (51.55)	3.94×10^{-3} (5.55)	2.24×10^{-2} (31.55)	3.11×10^{-2} (43.80)	3.81×10^{-3} (5.37)		2.41×10^{-2} (33.94)
Coefficient of Variation %	134.24	38.53	162.25	126.49	139.09		75.65
Minimum cm/s (in/hr)	2.55×10^{-3} (3.59)	7.17×10^{-3} (10.10)	5.64×10^{-4} (0.79)	5.49×10^{-3} (7.73)	4.05×10^{-4} (0.57)	7.91×10^{-2} (111.4)	1.23×10^{-2} (17.32)
Maximum cm/s (in/hr)	9.08×10^{-2} (127.9)	1.54×10^{-2} (21.69)	3.97×10^{-2} (55.92)	6.05×10^{-2} (85.21)	7.14×10^{-3} (10.06)	8.81×10^{-2} (124.1)	5.87×10^{-2} (82.68)

Table 17: Statistics for Measured K_{sat} Values for 55 MPD Tests

Statistical Parameter	All MPD Tests
Number of Measurements	55
Mean - cm/s (in/hr)	1.81×10^{-2} (25.5)
Geometric Mean - cm/s (in/hr)	7.67×10^{-3} (10.80)
Median - cm/s (in/hr)	7.86×10^{-3} (11.07)
Standard Deviation - cm/s (in/hr)	2.30×10^{-2} (32.39)
Coefficient of Variation - %	127
Minimum - cm/s (in/hr)	2.69×10^{-4} (0.38)
Maximum - cm/s (in/hr)	9.08×10^{-2} (127.9)

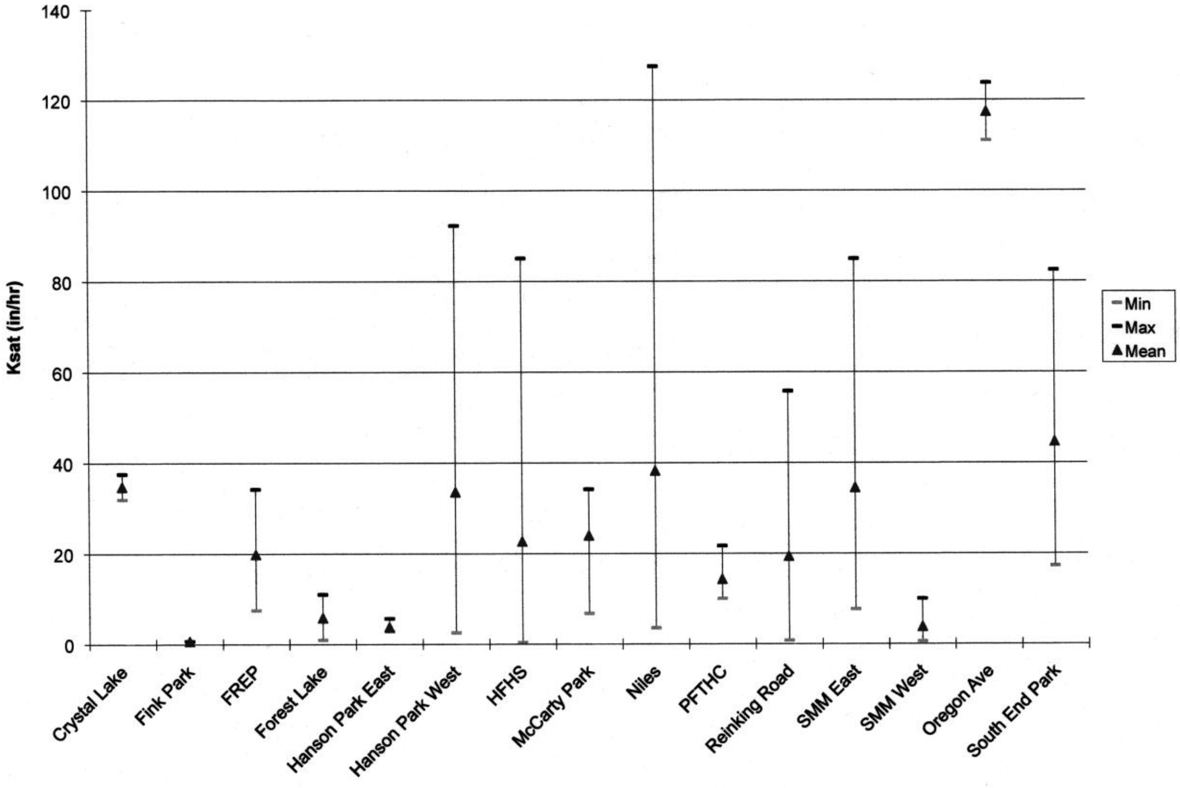

Figure 8: Average, Minimum, and Maximum K_{sat} Values by Site (in/hr)

The Oregon Avenue site had the highest mean K_{sat} value of $8.36x10^{-2}$ cm/s, which correlated to a surface infiltration rate of 301 cm/hr, or 118.52 in/hr. The K_{sat} values at Oregon Avenue ranged from $7.91x10^{-2}$ to $8.81x10^{-2}$ cm/s (111.4 to 124.1 in/hr). The K_{sat} values measured at Oregon Avenue represented the 2nd and 3rd highest K_{sat} values of the 55 tests. The exceptionally high K_{sat} values at this site can likely be attributed to the high organic content of the recently placed (spring/summer 2010) engineered soils utilized in the rain garden. During field testing, the soils were observed to be extremely loose which did not allow the MPD infiltrometer to firmly seal with the surface soils, thus potentially allowing water from the infiltrometer to leak laterally through the soils and overestimate infiltration rates at this site.

The highest individual K_{sat} value of $9.08x10^{-2}$ cm/s (127.9 in/hr) was measured at Niles. The mean K_{sat} value of the five samples taken at Niles was $2.73x10^{-2}$ cm/s (38.66 in/hr). The K_{sat} values at Niles ranged from $2.55x10^{-3}$ to $9.08x10^{-2}$ cm/s (3.59 to 127.9 in/hr). The high variability of the K_{sat} values obtained at Niles is attributed to the particular construction of this rain garden. The K_{sat} values decreased moving south through the rain garden from the inflow point towards the overflow riser. Based on observations made during the field testing, sand was the dominate soil type near the inflow of the rain garden but moving south towards the outfall, the soil type shifted from predominately sand to a more typical engineered soil mix of sand, compost, and topsoil. The high concentration of sand in the northern portion of the rain garden can explain the high variability seen in the K_{sat} values calculated for this site. A sixth MPD infiltration test was conducted near the overflow port of the Niles rain garden. However, as discussed above, a K_{sat} value was unable to be calculated for this sample as the field data did not meet the requirements of the data fitting requirements needed to calculate a K_{sat} value.

High variability of K_{sat} values within a rain garden were also seen at Homewood Flossmoor High School (HFHS), Hanson Park (West), St. Margaret Mary (SMM) (East), and South End Park. HFHS had a mean K_{sat} value of $1.62\text{x}10^{-2}$ cm/s (22.94 in/hr) with a range of $2.69\text{x}10^{-4}$ to $6.06\text{x}10^{-2}$ cm/s (0.38 to 85.4 in/hr). The HFHS site had two exceptionally high K_{sat} values – $6.06\text{x}10^{-2}$ cm/s (85.4 in/hr) in the northwest corner of the rain garden and $1.66\text{x}10^{-2}$ cm/s (23.38 in/hr) near the center of the rain garden. The lowest K_{sat} values (three samples), ranging from $2.69\text{x}10^{-4}$ to $3.19\text{x}10^{-3}$ cm/s (0.38 to 4.49 in/hr), were found in the deepest part of the rain garden. Based on conversations with the owner of the rain garden, this rain garden typically holds water in its deepest sections for several days after large storms. Although the rain garden had a mean K_{sat} value of $1.62\text{x}10^{-2}$ cm/s (22.94 in/hr), this may not be indicative of the overall performance of the rain garden, given that the primary storage area of the rain garden had a drastically lower K_{sat} value of $2.69\text{x}10^{-4}$ cm/s (0.38 in/hr). The lower K_{sat} values in the deepest part of the rain garden could have been caused by the clogging of the soil by sediment and other particulates that were able to fall out of the water when it was stored in this area.

Hanson Park (West) had the third highest mean K_{sat} value of $2.39\text{x}10^{-2}$ cm/s (33.67 in/hr) of the 15 gardens. A review of the three individual samples shows that two of the three sampling locations had K_{sat} values significantly lower than the average ($1.83\text{x}10^{-3}$ and $4.23\text{x}10^{-3}$ cm/s, or 2.58 and 5.96 in/hr). The third sample location had an exceptionally high K_{sat} value of $6.57\text{x}10^{-2}$ cm/s (92.54 in/hr). This K_{sat} value was the third highest calculated K_{sat} value of all 55 samples. The high variability between the three collected samples indicates that the average K_{sat} value for the Hanson Park (West) garden may have been exaggerated and is not indicative of its expected performance. Additional sampling in the Hanson Park (West) rain garden would need to be conducted to confirm this conclusion.

SMM (East) had a similar pattern of variability as that observed at Hanson Park (West). SMM (East) had the fifth highest mean K_{sat} value of $2.46\text{x}10^{-2}$ cm/s (34.6 in/hr) of the 15 gardens. A review of the three individual samples shows that two of the three sampling locations had K_{sat} values significantly lower than the average ($5.49\text{x}10^{-3}$ and $7.80\text{x}10^{-3}$ cm/s). The third sample location had an exceptionally high K_{sat} value ($6.05\text{x}10^{-2}$ cm/s, or 85.2 in/hr). This K_{sat} value was the fifth highest calculated K_{sat} value of all 55 samples. The high variability between the three samples at SMM (East) indicated that the average K_{sat} value for that garden may be exaggerated and a lower average K_{sat} value is more appropriate for the garden. Additional sampling in the SMM (East) rain garden would need to be conducted to confirm this conclusion.

The K_{sat} values at South End Park also exhibited high variability. South End Park had a mean K_{sat} value of $3.18\text{x}10^{-2}$ cm/s (45.10 in/hr) and the second highest average K_{sat} value of the 15 sites. The K_{sat} values at South End Park ranged from $1.23\text{x}10^{-2}$ to $5.87\text{x}10^{-2}$ cm/s (17.32 to 82.7 in/hr). The exceptionally high K_{sat} values and the high variability in the K_{sat} values may be attributed to the high organic content of the recently placed (spring/summer 2010) engineered soils utilized in the rain garden. During field testing, the soils were observed to be extremely loose, which did not allow the MPD Infiltrometer to firmly seal with the surface soils. This could allow water from the infiltrometer to leak laterally through the soils and overestimate infiltration rates at this site.

Another rain garden that had notable results was McCarty Park. McCarty Park had an average K_{sat} value of 1.71×10^{-2} cm/s (24.22 in/hr) with a K_{sat} value range of 4.85×10^{-3} to 2.44×10^{-2} cm/s (6.83 to 34.37 in/hr). The three lowest K_{sat} values measured were near the inlets to the rain garden. The lowest measured K_{sat} value of 4.85×10^{-3} cm/s (6.83 in/hr) was measured downstream of a curb-cut inlet in an area where vegetation was sparse. The second lowest K_{sat} value of 1.30×10^{-2} cm/s (18.3 in/hr) was measured downstream of a curb-cut inlet where vegetation was dense, and the third lowest K_{sat} value of 1.80×10^{-2} cm/s (25.35 in/hr) was measured near the storm sewer overflow inlet that drains into the rain garden. The lower K_{sat} values near the inlets could be attributed to the settling out of eroded clays or from compaction of the surface due to the inflow of stormwater into the rain garden. It is also important to note that the lowest K_{sat} value measured in the rain garden was in an area of sparse vegetation indicating that the presence of vegetation had a positive effect on infiltration rates, or that poor infiltration was having a negative effect on the vegetation.

In general, rain gardens that were constructed with engineered soils had higher K_{sat} values than rain gardens that were constructed in native soils. The average K_{sat} values for the gardens constructed with engineered soils was 2.69×10^{-2} cm/s (38.11 in/hr) when the Oregon Avenue site is included and an average K_{sat} value of 1.88×10^{-2} cm/s (26.6 in/hr) when Oregon Avenue is not included (due to the potentially exaggerated high infiltration rate related to the physical properties of the soils at that location). The average K_{sat} values of rain gardens constructed with native soils was 1.18×10^{-2} cm/s (16.7 in/hr). The rain gardens constructed with engineered soils had a 128% greater K_{sat} value (with Oregon Avenue included) or 59.4% greater K_{sat} value (without Oregon Avenue included) than those constructed in native soils.

Although the rain gardens constructed with engineered soil (a formulated mixture of materials having specific properties) had higher average K_{sat} values than rain gardens that were constructed in native soils, almost all of the native soil rain gardens performed better than would be predicted using NRCS soil survey data. The soil survey data for the rain gardens constructed in native soils is presented in Table 18.

The following points summarize our findings from the Level 2 infiltration testing:

- High variability of K_{sat} values were found when comparing testing locations within rain gardens. This variability was even seen in rain gardens constructed of engineered soils where soil conditions are expected to be similar throughout the garden.
- Lower infiltration rates were observed near the inflow and in the deepest portions of the rain gardens. These findings suggest that surface infiltration may decrease over time in these areas due to compaction of the soils caused by concentrated flows or the clogging of the surface soils through particle settling.
- High variability of average K_{sat} values was found across the 15 tested rain gardens.
- Rain gardens that were constructed with engineered soils had higher K_{sat} values than rain gardens that were constructed in native soils.
- Soils information presented in the NRCS soil survey may not be indicative of the performance of rain gardens constructed with native soils. All of the rain gardens had infiltration capacities greater than those indicated by the NRCS data.

Table 18: NRCS Soil Survey Data on Rain Gardens Designed with Native Soils

Parameter	**Crystal Lake**	**Fink Park**	**Forest Lake Commun. Center**	**Hanson Park**		**HFHS**	**PFTHC**
				East	**West**		
Calculated Data							
Mean K_{sat} (cm/s)	$2.48\text{x}10^{-2}$	$4.86\text{x}10^{-4}$	$1.42\text{x}10^{-2}$	$2.71\text{x}10^{-3}$	$2.39\text{x}10^{-2}$	$1.62\text{x}10^{-2}$	$1.02\text{x}10^{-2}$
Mean K_{sat} (in/hr)	34.78	0.68	20.00	3.82	33.66	22.82	14.37
NRCS Data							
Soil ID	369B	330A	232A	Unmapped	Unmapped	805B	330A
Soil Name	Waupecan Silt Loam	Peotone silty clay loam	Ashkum silty clay loam			Orthents clayey	Peotone silty clay loam
Drainage Class	Well drained	Very poorly drained	Poorly drained			Moderately well drained	Very poorly drained
K_{sat} of limiting layer	Moderatley high to high (0.6-2 in/hr)	Moderately high (0.2-0.6 in/hr)	Moderately high (0.2-0.6 in/hr)			Moderately low (0.02-0.06 in/hr)	Moderately high (0.2-0.6 in/hr)
Frequency of flooding	None	None	None			None	None
Frequency of ponding	None	High	Frequent			None	High

Synthetic Drawdown Testing (Level 3)

Each of the three selected sites was tested by filling at least a portion of the rain garden with water and recording how long it took for the garden to drain. The selected sites were McCarty Park (Site 8), Niles Community Rain Garden (Site 9), and South End Park (Site 15). Table 2 has a description of the sites, and Appendix C has an aerial photograph of each site.

McCarty Park is a roadside rain garden that is comprised of three cells divided from each other by a culvert. For the synthetic drawdown test, the most eastern cell was selected. This cell was separated from the rest of the rain garden by blocking the culvert with sandbags. The cell was then filled with 51 m^3 (13,465 gal) of water to a depth of 10.2 to 20.3 cm (4 to 8 in) using a fire hose. It took approximately 40 minutes to add the water to the rain garden. After the 40 min, there was still available storage in the rain garden but due to the large volume of water already added, the water flow was stopped. The time from the start of filling, the time to the end of filling, and the time to the complete drawdown of the rain garden were recorded. The deepest water was observed in the western portion of the rain garden closest to the blocked culvert. Synthetic drawdown time for the rain garden was 27 min 29 s. A Hobo Water Level Logger (water level meter) was installed in the center of the rain garden and collected water level readings every 10 s during the filling and drawdown of the rain garden. Additionally, visual observations were recorded. The bottom of the garden is somewhat undulating. In general, it took longer for the deepest part of the rain garden to drain than the shallower filled sections.

Considering that the rain garden did not drain uniformly, the data obtained from the water level meter placed in the center of the rain garden did not provide any information beyond what was visually observed.

The Niles Community rain garden was filled with 9.8 m^3 (2,600 gal) of water using a 5-cm (2-in) diameter hose connected to an adjacent fire hydrant. It took approximately 62 min to add the water. There was still available storage in the rain garden but, due to the volume of water already added and the staff time utilized, the water flow was stopped after 62 min. The time from the start of filling and the time to the end of filling were recorded. A Hobo Water Level Logger (water level meter) was installed near the overflow and collected water level readings every 10 s during the filling and drawdown of the rain garden. Visual observations were also recorded.

The deepest water was observed near the small overflow riser of the rain garden. During the filling of the rain garden, the sound of water flowing through a pipe could be heard near the outflow despite the fact that water was not observed flowing into the riser. A site representative assisting with the filling of the rain garden informed us that a perforated pipe was used to connect the outflow port to the adjacent storm sewer system. Based on the configuration of the rain garden, the perforated pipe was serving as an underdrain for the storage area of the rain garden located south of and adjacent to the riser. The quickest drawdown times were observed near the riser (8 min) and under the pedestrian bridge located in the center of the rain garden (7 to 9 min). Considering that the rain garden did not drain uniformly, the data obtained from the water level meter placed at the riser did not provide any information beyond what was visually observed.

The South End Park rain garden was filled with 1.1 m^3 (300 gal) of water using a water truck. The water truck was the only available source of water for the drawdown testing. It took 23 minutes to empty the water truck into the rain garden. The time from the start of filling, the time to the end of filling, and the time to the complete drawdown of the rain garden were recorded. Additionally, visual observations were recorded. At no time during the test did any water pond in the rain garden. Thus, there was no way to measure the drawdown.

Conclusions

Bioswale Performance Monitoring at Our Lady Gate of Heaven Parish

The objective of the monitoring at Our Lady Gate of Heaven was to compare the performance of the bioswale during the winter months of 2009/2010 with the performance during the sampling conducted during the fall of 2007 and the spring and summer of 2008. The data collected between December 15, 2009, and February 9, 2010, indicated that the winter conditions did not negatively impact the performance of the bioswale. The infiltration rate of the bioswale was determined to be 2.70×10^{-4} cm/s (0.38 in/hr), which is well within the infiltration rates of 1.42×10^{-4} to 5.68×10^{-4} cm/s (0.2 to 0.8 in/hr) documented during warmer months. Additionally, as observed during the summer months, the infiltration rate of the swale during the winter months was limited by the infiltration rate of the subsoils and not of the engineered soils or aggregate, indicating that frozen surface conditions did not negatively impact the infiltration rate of the bioswale.

Permeable Concrete Monitoring at St. Margaret Mary Parish

The initial infiltration rates measured at St. Margaret Mary in July 2009 were significantly less than rates measured on comparable permeable concrete pavements. Based on recommendations from the permeable concrete manufacturer, the concrete was cleaned by power washing and the infiltration rates were re-measured. An increase in infiltration rates to an average of 1.96×10^{-2} cm/s (27.58 in/hr) on the east section and 1.37×10^{-2} cm/s (19.3 in/hr) on the west section was observed following the cleaning in October 2009. These rates were acceptable, although recent improvements in the paving design have yielded significantly higher rates. However, another significant decrease in infiltration rates was observed between October 2009 and March 2010 (26.18% decrease in the east section and 38.84% decrease in the west section). These results indicate that a routine cleaning schedule may be required to maintain the functionality of permeable pavement sections. The use of an infiltrometer similar to the one constructed for this project could be an affordable and simple way to develop and implement a maintenance plan to ensure the long-term functionality of permeable pavement.

Based on the results of the flowpath assessment, it appears that the existing slope of the traditional asphalt paved portion of the parking lot causes concentrated flow to reach the permeable pavement sections at discrete locations. The combination of the velocity of the concentrated flow and the lower than expected surface infiltration rates of the permeable pavement allowed the water to rapidly bypass the surface of the permeable pavement (and an opportunity for infiltration) and discharge into the sewer system. These findings indicate that, depending on the existing slopes in a parking lot, it may be not be feasible to install permeable pavement sections in a parking lot and be able to infiltrate 100% of the runoff from the parking lot. In order to infiltrate a significant portion of the parking lot runoff during moderate rain events, grading to break up the discrete flow paths in addition to the installation of the permeable concrete sections may be necessary. However, if the entire surface of the permeable pavement is covered with water during major rain events, substantial reductions in the flow to the sewer may be achieved. Attention must be paid to the details of the connections between the impermeable pavement and the permeable pavement.

Regional Inventory of BMPs and Monitoring of Rain Gardens

The infiltration rate of a rain garden's soils is one of the most critical characteristics to monitor in order to document how well the rain garden is functioning to manage stormwater runoff. There are numerous devices and methods that have been developed for measuring infiltration rates and to compute saturated hydraulic conductivity (K_{sat}). The goal of this project was to use three alternative and complimentary approaches to assess the performance of rain gardens in Northeastern Illinois.

The three approaches included: (1) visual inspection, (2) infiltration rate testing, and (3) synthetic drawdown testing. These approaches were chosen because we wished to determine how easily they could be employed by others who are planning, designing, and/or maintaining stormwater BMPs.

Visual assessment of approximately 70 rain gardens, bioswales, and permeable pavement revealed a variety of maintenance conditions that needed attention. There were no cases, however, where lack of maintenance appeared to affect the performance of the feature regarding infiltration. Routine maintenance practices should result in features that perform satisfactorily for many years.

The infiltration rate testing conducted as part of the project focused on the use of an MPD Infiltrometer. The MPD Infiltrometer offers numerous benefits including that it is relatively easy and inexpensive to construct, it requires a low volume of water to operate, and it's easy to use. The K_{sat} data obtained in the project through the use of the MPD Infiltrometer provided a preliminary indication of the ability of the rain garden to infiltrate runoff. A significant finding was the variability of infiltration rates across the 15 tested rain gardens and within each specific rain garden. High variability of K_{sat} values were found within many of the tested rain gardens. As other research has shown, multiple tests are needed to reasonably quantify rain garden performance (Asleson et al., 2009). Of particular interest was the trend that decreased infiltration rates were observed near the inflow and in the deepest portion of the rain gardens. These findings suggest that surface infiltration may decrease over time due to compaction of the soils caused by concentrated flows or the clogging of the surface soils through particle settling. Use of the MPD Infiltrometer can easily track rain garden performance over time and assist in the development and implementation of maintenance plans to ensure long-term success of the rain gardens.

It should also be noted that the K_{sat} values measured during this project are estimates and only represent the infiltration rate of the surface soil layer. The calculated average K_{sat} values may not accurately predict rain garden performance if a subsoil with a much lower K_{sat} value is present below the surface soils. Additional MPD Infiltrometer testing of the subsoils through the use of test pits could be beneficial in the design or in estimating infiltration rates of existing rain gardens.

There is a potential explanation that has not been mentioned for the variability of the soils in the rain gardens. It is likely that many of the gardens do not contain natural soils. The Crystal Lake, Niles, Hansen Park and St. Margaret Mary sites, among others, are very urbanized and it would be surprising if their soils had never been greatly disturbed. Some of the gardens, such as Homewood Flossmoor and Highland Park, appear likely to have been built on areas filled during construction of nearby buildings, in which case they could be on tight soils that have been heavily compacted in the past.

During the execution of the synthetic drawdown tests, it was quickly learned that the feasibility of synthetic drawdown testing can be a significant barrier to properly conducting the tests. At the start of the project, we intended to select several smaller rain gardens - less than 46.5 m^2 (500 ft^2) in size – with a variety of soil types (native as well as engineered) and age. However, the rain gardens selected for drawdown testing in the project were based solely on the availability of a water source. It was much more difficult than was originally expected to identify site contacts that were willing to provide a water source and dedicate staff time to the project. Several of our preferred sites did not have an adequate water supply (such as a fire hydrant) in close vicinity.

Performance of Stormwater Best Management Practices

The overall conclusions of this project are:

1. A bioswale can be an effective method of infiltrating stormwater from a large impervious surface. The limits to its performance may be the permeability of underlying soils. However, if there are existing drainage structures to serve as a backup system, the bioswale can be utilized with confidence.
2. Permeable pavement can also be an effective method of infiltrating stormwater from a parking lot. It can be utilized with confidence if it is placed surrounding existing drainage structures and if there is a maintenance program that presents clogging.
3. A rain garden can be an effective method of infiltrating stormwater from a roof or other impermeable surface. While soil conditions vary greatly throughout the region, and often vary substantially within a single rain garden, they can be used with confidence as long as caution is taken not to divert water toward a vulnerable situation.
4. Soil analysis may not be a reliable way to predict the performance of a rain garden. One or even several soil borings or infiltrometer tests may not accurately measure the average soil conditions throughout the rain garden.
5. Despite the many reasons often given to doubt the capacity of our soils to infiltrate stormwater, rain gardens are nearly always successful. For example, one measure of success could be the capacity of a rain garden to infiltrate a 100-year storm event from a tributary area six times larger than the garden. Thus, a garden could be considered effective if it infiltrates seven inches of rainfall from an area six times the garden’s area plus the area of the rain garden, or the equivalent of 49 inches during a 24-hour storm. Our testing indicated that all but one of the 15 rain gardens tested would successfully infiltrate the water from a 100-year storm event.

Recommendations

1. We recommend that the use of bioswales, permeable pavement, and rain gardens be widely used in the Chicago region. When designed in accordance with the findings in this project, they can be used with confidence.
2. Municipalities and other agencies with authority over stormwater management should develop policies and practices that encourage the use of infiltration as a preferred choice of methods for reducing runoff rates and volumes.
3. The results of this project can have a very significant effect on the acceptance of green infrastructure as a preferred practice for urban and suburban stormwater management. After acceptance by ISTC, this report will be made available to the public in several ways:

    - It will be submitted by CNT and Hey to at least one professional journal.
    - It will be incorporated into the CNT Green Values Calculator website www.greenvalues.cnt.org.
    - It will be utilized at professional conferences.
    - ISTC will publish it and make it available on its website.

The project identified future monitoring needs that would refine the methods of this project and obtain additional data on the performance of rain gardens in Northeastern Illinois. These research needs are:

- Conducting additional synthetic drawdown testing on smaller rain gardens and/or rain gardens with lower average K_{sat} values to confirm that K_{sat} values obtained from MPD Infiltrometer testing are indicative of actual drawdown times.
- Conducting additional MPD Infiltrometer testing on soils adjacent to rain gardens. In order to conduct this testing, a second MPD Infiltrometer constructed of metal to facilitate its installation into stiffer soils would need to be constructed.
- Conducting additional MPD Infiltrometer testing on rain garden subsoils. This could be accomplished by installing the infiltrometer in a 30 to 45-cm (12 to 18 in) deep test pit.
- Conducting additional synthetic drawdown testing at several sites to establish a stronger connection between estimated infiltration rates (using MPD Infiltrometer testing and NRCS Soil Survey information) and actual rain garden performance.

While this research is recommended, we do not recommend delaying the promotion of green infrastructure facilities until further research has been completed.

We recommend that ISTC and other agencies support the continued inventory of green infrastructure in the Chicago Region. CNT is working with Great Lakes and national agencies and cities to encourage similar projects in other locations to document their green infrastructure and this work is informing those efforts.

We also recommend that ISTC and other agencies support continued monitoring of green infrastructure so that the evidence of their benefits and cost-effectiveness grows and contributes to their increasing utilization.

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Appendix A:
Survey Request for
Green Infrastructure Inventory

The message below was used to notify people about the Green Infrastructure Inventory and to gain their input.

I'm writing to share with you some exciting news for Chicago area green infrastructure practitioners and enthusiasts.

The Center for Neighborhood Technology (CNT) has received funding from the Illinois Sustainable Technology Center (ISTC) to create an inventory of green infrastructure features in the Chicago region, as part of our effort to identify sites at which to test the effectiveness of green infrastructure and better understand green infrastructures benefits for storm water management, community vitality and health. We'll be publicizing the results of our tests and the inventory itself so that others wishing to learn more about green infrastructure will know where to look. Please take a moment to tell us about the green infrastructure features you know by clicking this link:
http://www.esurveyspro.com/Survey.aspx?id=e7f29394-415d-47c5-9a2f-44d3a887d159

Appendix B:
Visual Assessment Checklist

The survey that follows has been developed by the University of Minnesota and was utilized for visual assessment of the BMPs.

UNIVERSITY OF MINNESOTA

Stormwater Treatment: Assessment and Maintenance

Field Data Sheet for Level 1 Assessment: Visual Inspection Bioretention Practices (including Rain Gardens)

Inspector's Name(s):____________________
Date of Inspection:____________________
Location of the bioretention practice:____________________
Address or Intersection:____________________
Latitude, Longitude:____________________
Date the bioretention practice began operation: ____________________
Bioretention practice area (ft. x ft.): ____________________
Time since last rainfall (hr): ____________________
Quantity of last rainfall (in): ____________________
Rainfall Measurement Location: ____________________

Site Sketch (include inlets, outlets, north arrow, etc.)

Based on visual assessment of the site, answer the following questions and make photographic or video-graphic documentation:

1. Has visual inspection been conducted at this location before? ☐ Yes ☐ No ☐ I don't know
   1. a) If yes, enter date:____________________
   1. b) Based on previous visual inspections, have any corrective actions been taken?
      ☐ Yes ☐ No ☐ I don't know (If yes, describe actions in comments box)

2. Has it rained within the last 48 hours at this location? ☐ Yes ☐ No ☐ I don't know

3. Does this bioretention practice utilize pretreatment practices upstream?
   ☐ Yes ☐ No ☐ I don't know (If yes, describe pretreatment practices in comment box)

4. Access
   4. a) Access to the bioretention practice is:
      ☐ Clear ☐ Partially obstructed ☐ Mostly obstructed ☐ Inaccessible
   4. b) If obstructed, the obstruction is (choose and provide comments) :
      ☐ temporary **and** ☐ no action needed **or** ☐ action needed
      ☐ permanent **and** ☐ before or during installation **or** ☐ new since installation
   4. c) Access to the upstream and downstream drainage is:
      ☐ Clear ☐ Partially obstructed ☐ Mostly obstructed ☐ Inaccessible
   4. d) If obstructed, the obstruction is (choose and provide comments) :
      ☐ temporary **and** ☐ no action needed **or** ☐ action needed
      ☐ permanent **and** ☐ before or during installation **or** ☐ new since installation

Comments

5. Inlet Structures
   5. a) How many inlet structures are present? ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ > 5
   5. b) Are any of the inlet structures clogged? (If yes, mark location on site sketch above and fill in boxes below with items causing clogging (i.e.,. debris, sediment, vegetation, etc.)

	Inlet #:	Inlet #:	Inlet #:	Inlet #:	Inlet #:
Partially					
Completely					
Not Applicable					

   5. c) Are any of the inlet structures misaligned from the original design or otherwise in need of maintenance? (if yes, write in reason: frost heave, vandalism, unknown, etc.)

	Inlet #:	Inlet #:	Inlet #:	Inlet #:	Inlet #:
Reason					

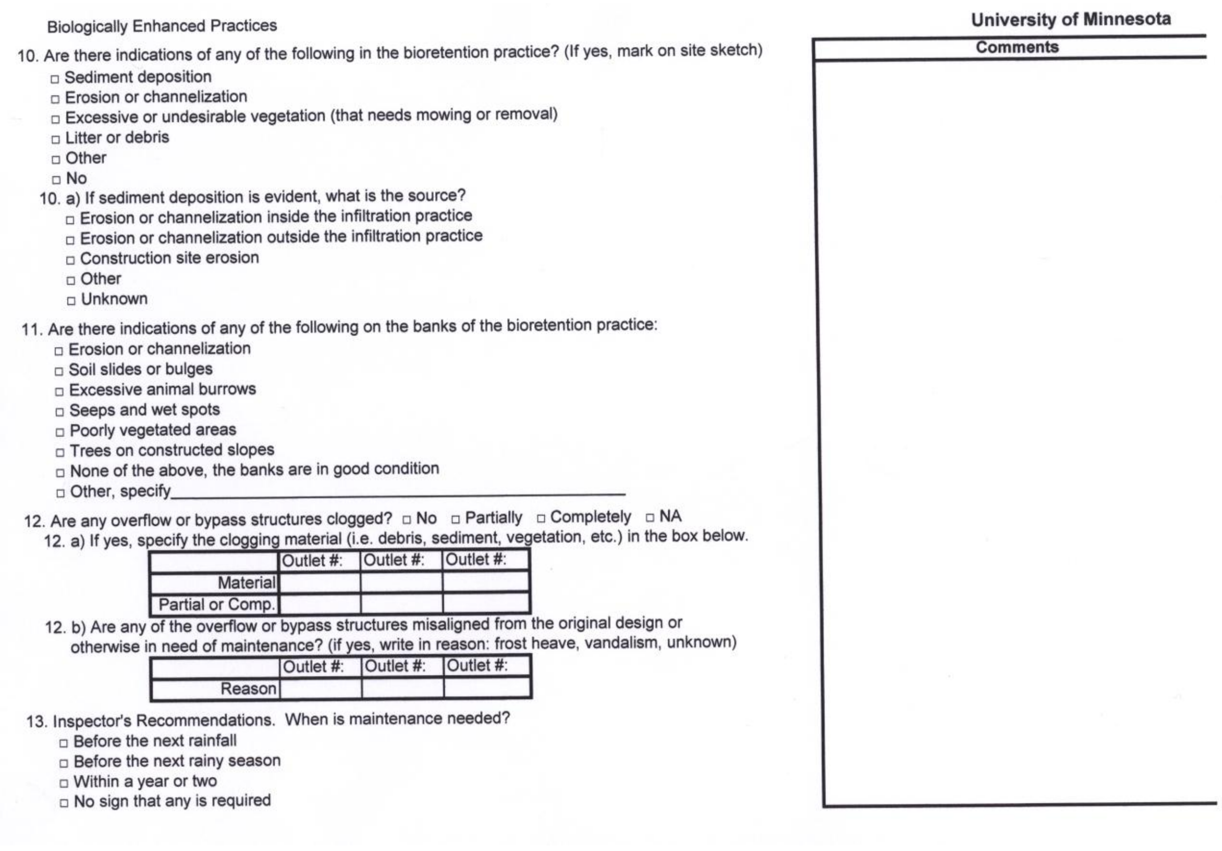
6. Is there standing water in the bioretention practice? ☐ Yes ☐ No
   6. a) If yes, does the water have:
      ☐ Surface sheen (from oils or gasoline)
      ☐ Murky color (from suspended solids)
      ☐ Green color (from algae or other biological activity)
      ☐ Other (describe In comment box)

7. Is there evidence of illicit storm sewer discharges?
   ☐ Yes ☐ No ☐ I don't know (if yes, describe in comment box)

8. Does the bioretention practice smell like gasoline or oil? ☐ Yes ☐ No

9. What is the approximate percentage of vegetation coverage in the practice? ________ %
   9. a) Does the current vegetation match the original design? ☐ Yes ☐ No ☐ Unknown
   9. b) Is there the presence of:
      ☐ Weeds
      ☐ Wetland vegetation
      ☐ Invasive vegetation
      ☐ None of the above
      ☐ Other, specify____________________
   9. c) Does the vegetation appear to be healthy? ☐ Yes ☐ No (if no, describe in comment box)
   9. d) Is the vegetation the appropriate size and density? ☐ Yes ☐ No (if no, describe in comment box)

Comments


Biologically Enhanced Practices

University of Minnesota

10. Are there indications of any of the following in the bioretention practice? (If yes, mark on site sketch)
    - ☐ Sediment deposition
    - ☐ Erosion or channelization
    - ☐ Excessive or undesirable vegetation (that needs mowing or removal)
    - ☐ Litter or debris
    - ☐ Other
    - ☐ No

10\. a) If sediment deposition is evident, what is the source?
  - ☐ Erosion or channelization inside the infiltration practice
  - ☐ Erosion or channelization outside the infiltration practice
  - ☐ Construction site erosion
  - ☐ Other
  - ☐ Unknown

11. Are there indications of any of the following on the banks of the bioretention practice:
    - ☐ Erosion or channelization
    - ☐ Soil slides or bulges
    - ☐ Excessive animal burrows
    - ☐ Seeps and wet spots
    - ☐ Poorly vegetated areas
    - ☐ Trees on constructed slopes
    - ☐ None of the above, the banks are in good condition
    - ☐ Other, specify____

12\. Are any overflow or bypass structures clogged? ☐ No ☐ Partially ☐ Completely ☐ NA

12\. a) If yes, specify the clogging material (i.e. debris, sediment, vegetation, etc.) in the box below.

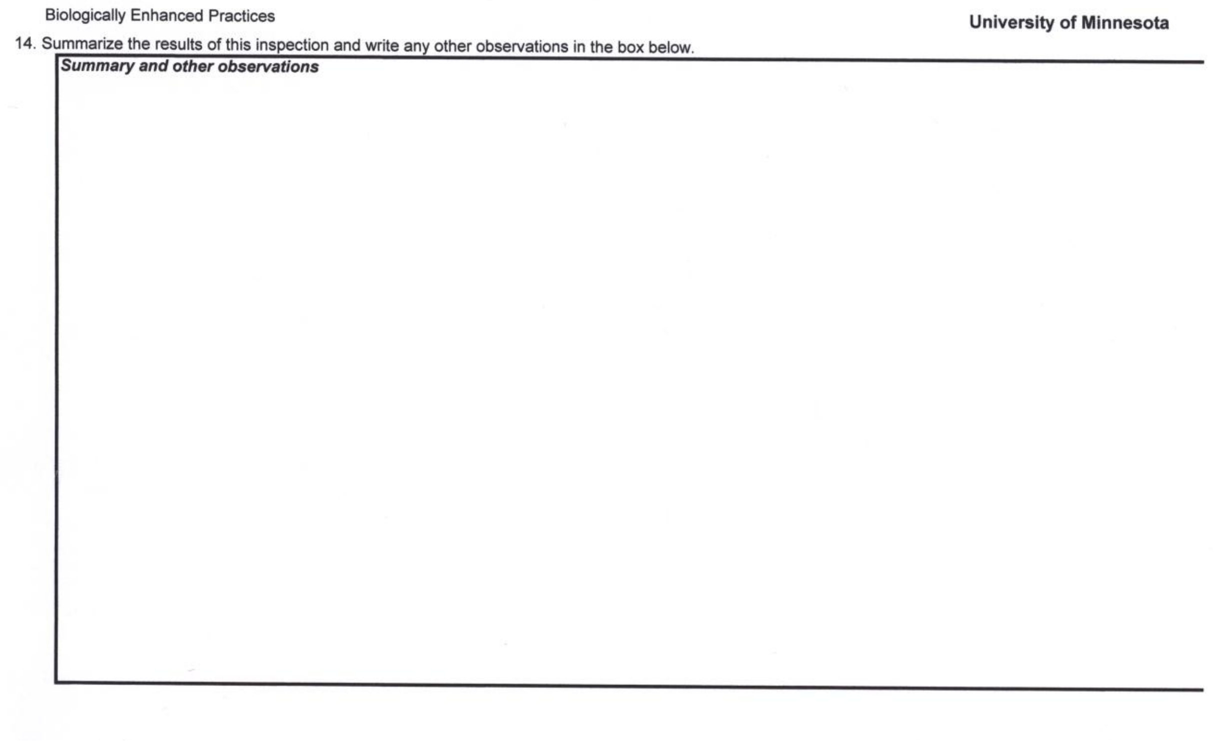
	Outlet #:	Outlet #:	Outlet #:
Material			
Partial or Comp.			

12\. b) Are any of the overflow or bypass structures misaligned from the original design or otherwise in need of maintenance? (if yes, write in reason: frost heave, vandalism, unknown)

	Outlet #:	Outlet #:	Outlet #:
Reason			

13\. Inspector's Recommendations. When is maintenance needed?
  - ☐ Before the next rainfall
  - ☐ Before the next rainy season
  - ☐ Within a year or two
  - ☐ No sign that any is required

Comments


Biologically Enhanced Practices

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14\. Summarize the results of this inspection and write any other observations in the box below.

Summary and other observations

Appendix C:
Aerial Photographs
of 15 Rain Garden Sites

These aerial photographs show the 15 rain garden sites. There are 13 photographs because two of the photographs contain two rain garden sites.

Figure C1: Crystal Lake, McHenry County, IL

Figure C2: Fink Park, Highland Park, Lake County, IL

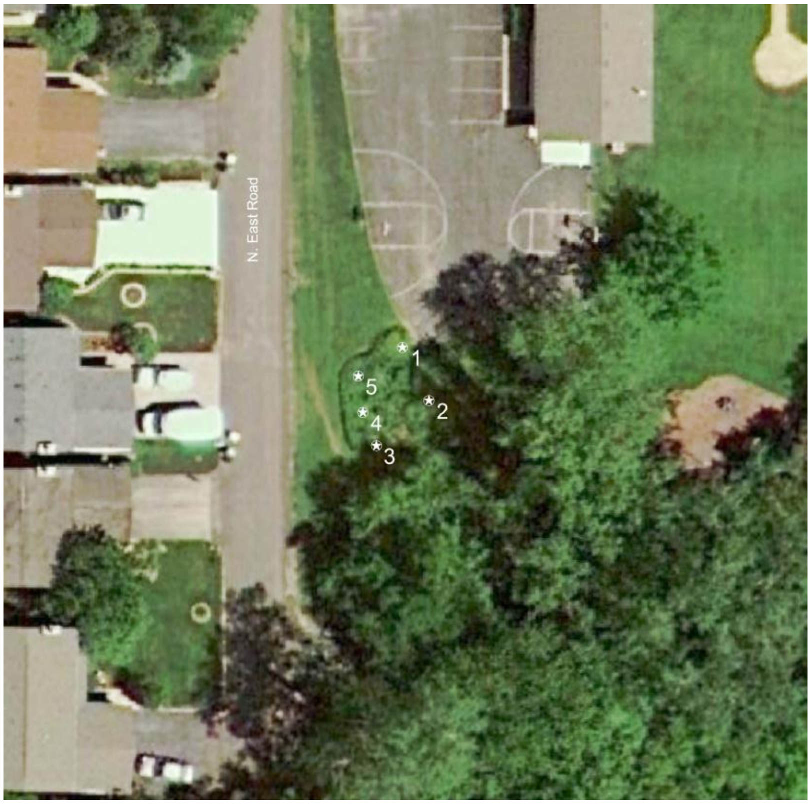

Figure C3: Forest Lake Community Center, Lake Zurich, Lake County, IL

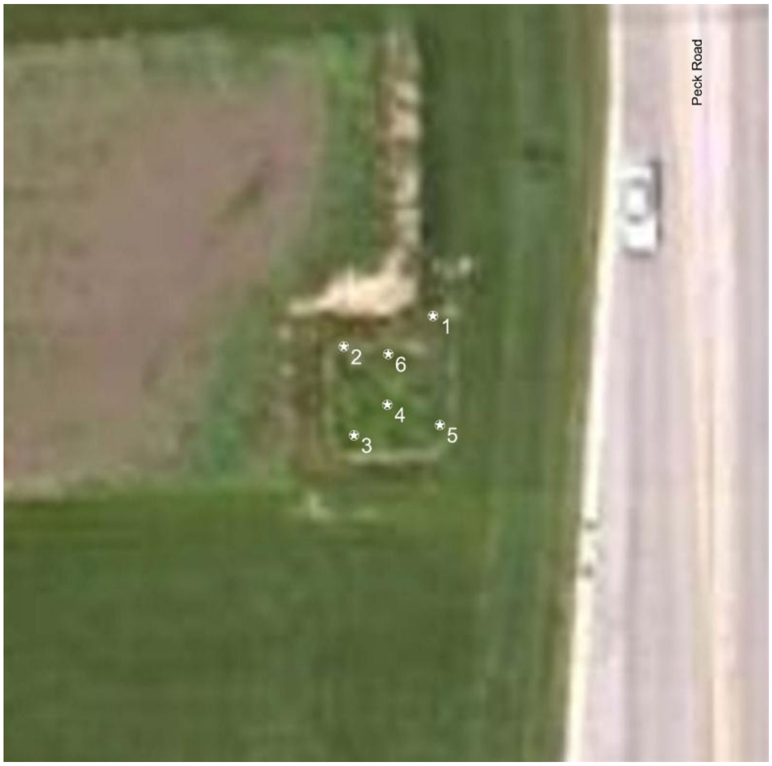

Figure C4: FREP, St. Charles, Kane County, IL

Figure C5: Hanson Park Elementary School (East and West), Chicago, Cook County, IL

Figure C6: Homewood Flossmoor High School, Flossmoor, Cook County, IL

Figure C7: McCarty Park, Aurora, Kane County, IL

Figure C8: Niles Community Garden, Niles, Cook County, IL

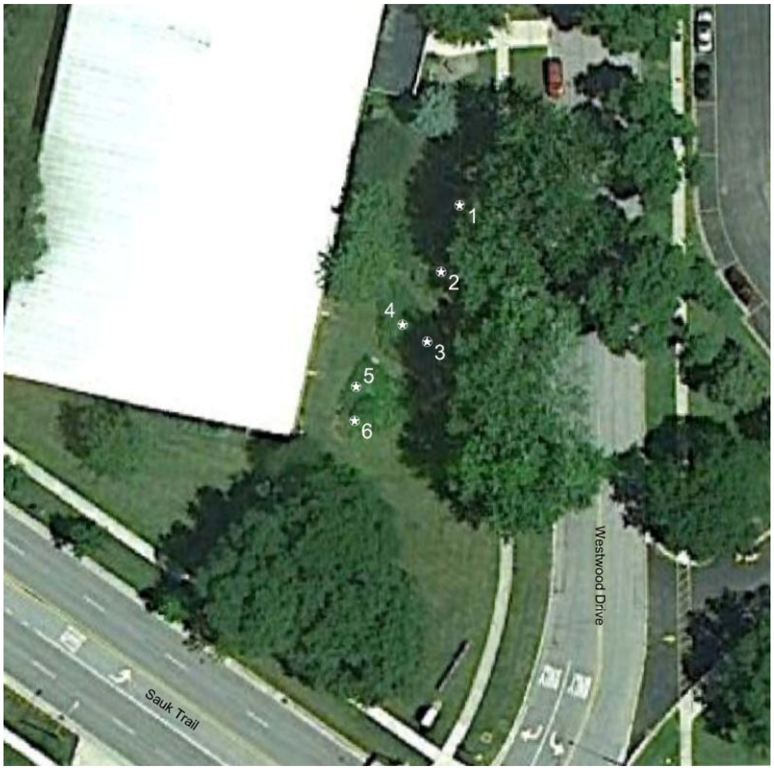

Figure C9: Park Forest Tennis & Health Club, Park Forest, Cook County, IL

Figure C10: Reinking Road, Pingree Grove, Kane County, IL

Figure C11: St. Margaret Mary (East and West), Chicago, Cook County, IL

Figure C12: Oregon Avenue, West Dundee, Kane County, IL

Figure C13: South End Park, West Dundee, Kane County, IL